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HUMAN EXPOSURE TO RADIOFREQUENCY RADIATION: A REVIEW PERTINENT TO AIR FORCE OPERATIONS

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13. ABSTRACT *(Maximum 200 words)*

This report is presents analyses of studies, research results, and other pertinent information related to investigations of human exposure to radiofrequency radiation (RFR). The topics discussed are the ANSI/IEEE RFR-exposure guidelines; environmental levels in 15 U.S. cities; and epidemiological/occupational studies, including positive and negative findings on general human health, congenital abnormalities, ocular effects, and reports of cancer incidence. Also discussed are studies in which human voluteers were exposed to RFR to investigate: the RFR-auditory effect, cutaneous perception of RFR, and RFR shock and burn. It is concluded that the human studies collectively provide no unequivocal scientific evidence that chronic exposure to RFR at intensities equal to or below those specified in the ANSI/IEEE exposure guidelines would be detrimental to humanhealth..

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[REVISION: 30 June 1994]

1 INTRODUCTION

1.1 GENERAL

This report is one of a planned series on various topics dealing with actual or possible biological effects of radiofrequency radiation (RFR) and their potential consequences regarding human health. In the report on each specific topic, critiques are presented of the research papers (in English) on that topic, selected predominantly from the peer-reviewed literature. This topical series includes revisions of, and additions to, the critiques, in Heynick (1987), of the then representative RFR-bioeffects papers published through about 1986, as well as critiques of subsequently published papers. With a few exceptions, presentations at scientific symposia or abstracts thereof were excluded from consideration in expectation that more detailed, peer-reviewed accounts of such studies will appear subsequently.

The acronym "RFR" used herein refers to the emission and propagation of electromagnetic waves in the frequency range nominally from 3 kHz to 300 GHz. Such waves are characterized as nonionizing radiation because the intrinsic (quantum) electromagnetic energy absorbed by a body at any frequency within this range is much too low to ionize (eject electrons from) molecules of the body. Equivalent terms found in the literature on RFR bioeffects include electromagnetic radiation (EMR), nonionizing radiation (NIR), nonionizing electromagnetic radiation (NIEMR), microwave radiation, microwave fields, radiofrequency electromagnetic (RFEM) fields, and electromagnetic fields (EMF). It should be noted, however, that the acronyms "EMF" (and "EM/F" for electric and magnetic fields) lately have become associated primarily with possible bioeffects of 50-Hz and 60-Hz electric and magnetic fields from powerlines and electrical appliances.

Endeavors were made to obtain and analyze virtually all of the peer-reviewed papers published to date on each topic. It is likely, however, that some papers were missed. If so, the authors of this report would be most appreciative of any suggested additions. Such papers, together with those published after this report is issued, may serve as the basis of a later update on those topics.

A number of papers on reported effects of electric and magnetic fields at frequencies below 3 kHz also were analyzed herein, mostly epidemiologic studies at powerline frequencies, because the reported findings appeared to be relevant to effects at RFR frequencies, or the occupations or other exposure conditions considered may have included frequencies in both realms. However, the inclusion of those papers is not intended to be an exhaustive treatment of possible bioeffects of powerline electric or magnetic fields, which may be the subject of a future report.

1.2 RFR SAFETY STANDARDS

Terms such as "safety standards" and "exposure standards" generally refer to, and are frequently used interchangeably with, specifications or guidelines on maximum permissible exposure levels to electromagnetic fields

for the general public or for those in occupations and/or in working areas where they may be periodically exposed to higher than background levels of such fields. In both situations, such levels are usually expressed as maximum permissible incident field intensities and/or power densities in specific frequency ranges for stated exposure durations.

In most guidelines for human exposure to RFR, the maximum permissible exposures (MPEs) are stated in terms of the maximum allowable incident power densities, expressed in milliwatts per square centimeter (mW/cm²) or in watts per square meter (W/m², with 1 W/m² = 0.1 mW/cm²). Such MPEs are selected on the basis of the highest values of "specific absorption rate" (SAR) that were found not to be harmful to animals in experimental studies. SAR is defined as the rate at which RFR energy is absorbed in any small volume of a body, and is usually expressed in watts per kilogram (W/kg) of the mass in that volume (or sometimes in milliwatts per gram, with 1 mW/g = 1 W/kg). For any specific value of incident power density, the SAR thus defined varies with location within the body, so it is frequently called the "local SAR".

Internal variations of SAR are difficult to determine for most complex bodies, so the term "whole-body SAR" is often used to represent the spatially averaged value of SAR for the body, a quantity that can be measured (e.g., by calorimetry) without a need to know the spatial variations of local SAR. The term "partial-body" or "part-body" SAR is used in appropriate cases, such as when absorption of RFR occurs primarily in a specific region of the body due to exposure from a nearby emitter (a hand-held transmitter for example).

For certain specified exposure conditions, such as at frequencies below about 300 MHz and/or within the "near-field" distance of an antenna emitting electromagnetic energy, it is usually necessary to consider the electric and magnetic fields separately. For such conditions, exposure guidelines are expressed in terms of maximum allowable electric fields in volts per meter (V/m) and/or maximum allowable magnetic fields in amperes per meter (A/m). Again, such guidelines are based on whole-body or part-body SARs.

Voluntary occupational guidelines and/or guidelines for exposure of the general public to RFR have been developed by various organizations, and such guidelines are reexamined for possible revisions on a cyclic schedule usually encompassing several years.

In 1974, the American National Standards Institute (ANSI) had published a standard (ANSI, 1974) applicable to those occupationally exposed to RFR and to exposure of the general public to RFR. Such exposures were not to exceed 10 mW/cm² or the equivalent electric and magnetic field strengths (200 V/m and 0.5 A/m, respectively) independent of frequency over the entire range 10 MHz to 100 GHz. The Federal Occupational Safety and Health Administration (OSHA), which had promulgated the 10-mW/cm² level as a voluntary occupational standard, subsequently found that the standard was legally unenforceable.

In 1982, ANSI had issued a revision (ANSI, 1982) of the 1974 guidelines, also applicable to both occupational and general-public exposure, based on critical analyses of the then current knowledge about the biological effects of RFR. The highest allowable incident field strengths or plane-wave equivalent power densities were based on a maximum whole-body SAR of 4 W/kg, which rendered those allowable levels frequency-dependent; the range covered

by ANSI (1982) was 300 kHz to 100 GHz. The 4-W/kg SAR was the level at or above which significant detrimental effects were observed in experimental studies with laboratory animals. A safety factor of 10 was incorporated in the ANSI (1982) guidelines, reducing the maximum allowable SAR to 0.4 W/kg. As in ANSI (1974), the limits in ANSI (1982) were not to be exceeded for exposures averaged over any six-minute period. At 0.4 W/kg, the smallest maximum allowable incident power density was 1 mW/cm² for the subrange 30-300 MHz, in which RFR absorption by the human body as a resonant entity (much like a dipole antenna) is highest.

In 1988, the functions of the various ANSI subcommittees on developing guidelines for RFR-exposure were transferred to Subcommittee IV of Standards Coordinating Committee (SCC) 28, a new body under the jurisdiction of the Institute of Electrical and Electronics Engineers (IEEE). SCC 28 produced a revision of the 1982 ANSI guidelines, based on the selection and analyses of the important research papers in an updated data base of the RFR-bioeffects literature. The revision, "IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz," was approved by the IEEE in 1991 and published in 1992. It was also approved by ANSI in 1992, and is referred to herein as the ANSI/IEEE (1992) guidelines.

As in ANSI (1982), the ANSI/IEEE (1992) guidelines, expressed in terms of MPEs, are largely based on 0.4 W/kg (4 W/kg reduced by a safety factor of 10). They cover the frequency range from 3 kHz to 300 GHz (instead of 300 kHz to 100 GHz), and separately specify MPEs in "uncontrolled environments" (in areas accessible by the general population) and in "controlled environments" (such as occupational exposure). The guidelines for controlled environments and uncontrolled environments are displayed in Tables 1 and 2, respectively. The averaging times are given in minutes.

TABLE 1: ANSI/IEEE (1992) MAXIMUM PERMISSIBLE EXPOSURE LIMITS FOR CONTROLLED ENVIRONMENTS*

Frequency Range (MHz)	E (V/m)	H (A/m)	Power Density, S (mW/cm²)	Averaging Time $\|E\|^2$, $\|H\|^2$, or S
0.003 - 0.1	614	163	**	6
0.1 - 3.0	614	16.3/f	**	6
3 - 30	(1 842)/f	16.3/f	**	6
30 - 100	61.4	16.3/f	**	6
100 - 300	61.4	0.163	1.0	6
300 - 3 000			f/300	6
3 000 - 15 000			10	6
15 000 - 300 000			10	$(616\ 000)/f^{1.2}$

TABLE 2: ANSI/IEEE (1992) MAXIMUM PERMISSIBLE EXPOSURE LIMITS FOR UNCONTROLLED ENVIRONMENTS*

Frequency Range (MHz)	E (V/m)	H (A/m)	Power Density, S (mW/cm^2)	Averaging Time $\|E\|^2$, S	Averaging Time $\|H\|^2$
0.003 - 0.1	614	163	**	6	6
0.1 - 1.34	614	16.3/f	**	6	6
1.34 - 3.0	823.8/f	16.3/f	**	$f^2/0.3$	6
3.0 - 30	823.8/f	16.3/f	**	30	6
30 - 100	27.5	$158.3/f^{1.668}$	**	30	$0.0636f^{1.337}$
100 - 300	27.5	0.0729	0.2	30	30
300 - 3 000			f/(1 500)	30	
3 000 - 15 000			f/(1 500)	(90 000)/f	
15 000 - 300 000			10	$(616\ 000)/f^{1.2}$	

*In both tables above, the exposure values in terms of electric and magnetic field strengths are the values obtained by spatially averaging values over an area equivalent to the vertical cross section of the human body (the projected area).

**The equivalent plane-wave power densities for E (V/m) and H (A/m), expressed in W/m^2, can be calculated from the equations $S = E^2/377$ and $S = 377H^2$, where 377 (ohms) is the impedance of free space. To obtain the corresponding values of S in mW/cm^2 as shown in the tables, divide the values expressed in W/m^2 by 10. Note that even though such calculated equivalent power densities are not appropriate for near-field conditions, they are useful for comparing them with the power density limits for the higher frequency ranges.

For controlled environments, those guidelines also specify the following limits on pulsed RFR:

> In the frequency range 0.1 to 300 000 MHz, the peak temporal MPE, expressed in terms of the electric field, is 100 kV/m. For single RFR pulses of duration less than 100 milliseconds in this frequency range, the peak MPE is given by the E-field equivalent power-density MPE of Table 1 in the formula:
>
> Peak MPE = MPE x averaging time / (5 x pulse duration).
>
> A maximum of five such pulses, with a pulse repetition period of at least 100 milliseconds, is permitted during any period equal to the averaging time.
>
> For pulse trains of more than 5 pulses or for pulse durations that exceed 100 milliseconds, the following formula applies for averaging over any 100-millisecond period:
>
> Σ Peak MPE x pulse duration = MPE x averaging time / 5.

Also included in the ANSI/IEEE (1992) guidelines are maximum allowable values of radiofrequency current flow induced within the feet of a person immersed in an RFR field or by a person's contact with an inanimate object

(such as a fence or vehicle) electrically charged by immersion in an RFR field. The limits for controlled and uncontrolled environments, respectively shown in Tables 3 and 4, are applicable only within the frequency range from 3 kHz to 100 MHz (where such effects can occur). Studies that served as the basis for those limits are discussed in Section 3.3 herein.

TABLE 3: ANSI/IEEE (1992) LIMITS ON INDUCED AND CONTACT CURRENTS IN CONTROLLED ENVIRONMENTS

Frequency Range (MHz)	Maximum Current (mA)		
	Through both feet	Through each foot	Contact
0.003 - 0.1	(2 000)f	(1 000)f	(1 000)f
0.1 - 100	200	100	100

TABLE 4: ANSI/IEEE (1992) LIMITS ON INDUCED AND CONTACT CURRENTS IN UNCONTROLLED ENVIRONMENTS

Frequency Range (MHz)	Maximum Current (mA)		
	Through both feet	Through each foot	Contact
0.003 - 0.1	900f	450f	450f
0.1 - 100	90	45	45

The ANSI/IEEE (1992) guidelines also specify conditions under which MPEs may be exceeded in controlled and uncontrolled environments, such as for part-body exposures, and indicate exclusions for exposures from devices that emit RFR of low power.

For several years, the Environmental Protection Agency (EPA) had been planning to issue RFR-exposure guidelines for the general population. The rationale for those guidelines was to be based on a literature review by Elder and Cahill (1984). On 30 July 1986, EPA had published a *Notice of Proposed Recommendations* (EPA, 1986) in which three options based on risk, benefit, and cost analyses were proposed: a tenfold, fivefold, or no reduction from 0.4 W/kg (i.e., to 0.04, 0.08, or 0.4 W/kg). However, the EPA later decided not to issue such exposure guidelines for the general population, and it has not done so to date. Subsequently, citing limited budgets and higher priorities in other environmental issues, the EPA began phasing out its research on RFR-bioeffects, which led to the virtual elimination of the program.

In the interim, the Federal Communications Commission (FCC) has required as a condition of licensing that operators of all transmitters licensed by the FCC certify that they meet the requirements of the ANSI (1982) standard, thus rendering it a mandatory rather than a voluntary federal standard. The FCC is now in the process of adopting the ANSI/IEEE (1992) standard to replace the ANSI (1982) standard.

In the absence of an overall mandatory Federal exposure standard (but not necessarily for that reason), various state, county, and municipal bodies have promulgated ordinances on exposure of the general population to RFR that are usually more stringent than those of ANSI (1982) or ANSI/IEEE (1992). Most such standards use 4 W/kg (the SAR basis of the 1982 ANSI guidelines), but with a safety reduction factor of 50 [to 0.08 W/kg] instead of 10.

More recently (on 26-27 April 1993), the EPA conducted a workshop in Bethesda, MD, to review the current status of research on biological effects of RFR. Formal presentations were given by invited experts on various topics, including dosimetry, magnetic resonance imaging (MRI), thermal physiology, epidemiology, and a general review of the scientific literature. The formal presentations were followed by workshops on those and other topics, and then by summaries at a plenary session. Last, the Chair of the plenary session (a member of the EPA's Science Advisory Board) proposed the following two-part motion, which was overwhelmingly approved by those present:

1) That the EPA resume its activities on RFR-bioeffects research with the intent of establishing a national standard for RFR-exposure.

2) That in the interim, the EPA adopt the ANSI/IEEE (1992) standard.

Other bodies in the USA and in other countries have issued exposure guidelines and/or are engaged in the cyclic process of revising previously published guidelines.

1.3 MEASUREMENTS OF ENVIRONMENTAL LEVELS OF RFR IN SELECTED U.S. CITIES AND AT SPECIAL LOCATIONS

More than a decade ago, the EPA had measured the environmental field intensities at selected locations in 15 U.S. cities. Even though a long time has elapsed since those measurements, the data remain valuable in the absence of comprehensive subsequent measurements.

The sites in each city were selected to permit analyses and estimations of cumulative fractions of the total population in each city exposed at or below various average power densities, based on the population figures derived from the 1970 census-enumeration districts. Tell and Mantiply (1980) and Janes (1979) presented the results for those cities (a total of 486 sites). Those results were also summarized in Hankin (1985) and in EPA (1986).

Measurements of field intensity were made at 6.4 m (20 ft) above ground at each site in the following frequency ranges (Janes et al., 1977): 0.5-1.6 MHz (the standard AM-radio broadcast band), 54-88 MHz and 174-216 MHz (the VHF-TV bands), 88-108 MHz (the standard FM-radio broadcast band), about 150 and 450 MHz (land-mobile bands), and 470-890 MHz (the UHF-TV bands). The signals in each band were received with separate antennas specifically designed for each band. However, measurements in the standard AM-radio broadcast band were not included in the analyses because that band was below the then prevailing 10-MHz lower frequency limit of the 1974 ANSI standard.

The measured field strengths at each site were integrated over the frequency bands (54 to 890 MHz) included in the analyses and converted into equivalent average power densities. The site values in each city were then used, with the population figures for the census enumeration districts, in a statistical model designed to estimate the population-weighted median exposure value for that city, and for calculating other statistics of interest.

The population-weighted median value for each city was defined as the average power density at or below which half the population of the city was being exposed. The estimates were based on the assumption that the people

were under continuous exposure at their place of residence; the estimates did not try to account for population changes since the 1970 census, population mobility, exposure at heights greater than 6.4 m (20 ft), attenuation of signals by buildings, or periods of time when any of the contributing RFR sources were not transmitting. The fifteen cities and their median values are shown in Table 5:

TABLE 5: ESTIMATED POPULATION EXPOSURES FOR 15 U.S. CITIES
[Tell and Mantiply (1980)]

City	Median Exposure ($\mu W/cm^2$)	Percent Exposed to Less Than 1 $\mu W/cm^2$
Boston	0.015	98.50
Atlanta	0.016	99.20
Miami	0.0070	98.20
Philadelphia	0.0070	99.87
New York	0.0022	99.60
Chicago	0.0020	99.60
Washington	0.009	97.20
Las Vegas	0.012	99.10
San Diego	0.010	99.85
Portland (Oregon)	0.020	99.70
Houston	0.011	99.99
Los Angeles	0.0048	99.90
Denver	0.0074	99.85
Seattle	0.0071	99.81
San Francisco	0.002	97.66
All cities	0.0048	99.44

The median exposures ranged from 0.002 $\mu W/cm^2$ (for San Francisco and Chicago) to 0.020 $\mu W/cm^2$ (for Portland) and the population-weighted median for all 15 cities was 0.0048 $\mu W/cm^2$. Also, the percentages of the population exposed to less than 1 $\mu W/cm^2$ in each city ranged from 97.2% (for Washington, D.C.) to 99.99% (for Houston), with a mean for all cities of 99.44%. The major contributions to those exposure values were from FM-radio and TV broadcast stations.

In the context of human exposure to environmental levels of RFR, many people are unaware that at normal body temperature, all of us are emitters of electromagnetic energy. Based on the well established physics principle of "black-body" radiation and assuming an emissivity of 1, Osepchuk (1990) [page 543] has calculated that at 98.6 °F (37 °C or 310 °K), a body emits continuous radiation that peaks in the infrared region (at a wavelength of approximately 12 micrometers), and that in the RFR part of the emission curve (continuous frequency range up to about 300 GHz), the emission level of the body is about 0.3 $\mu W/cm^2$. Osepchuk (1990) also cites several calculations by others, based on the same principle, that are erroneous.

The EPA also measured RFR levels at sites close to single or multiple RFR emitters, for example, at the bases of transmitter towers and at the upper stories (including the roof) of tall buildings or hospital complexes in the vicinity of transmitter towers. At the base of an FM tower on Mount Wilson, CA, the fields were found to range from the equivalent of about 1 to 7 mW/cm^2

(Tell and O'Brien, 1977). Most measurements in tall buildings near FM and TV transmitters yielded values well below 0.01 mW/cm² (10 μW/cm²), but a few values were close to or slightly exceeded 0.2 mW/cm² (e.g., 0.23 mW/cm² on the roof of the Sears Building, Chicago).

In Hawaii, however, considerably higher levels were found subsequently by EPA and Federal Communications Commission (FCC) personnel in a few sites very close to AM (550 kHz to 1.5 MHz) broadcast towers and FM (88-108 MHz) broadcast towers (MICROWAVE NEWS, January/February 1985). The highest levels were in the vicinity of several AM-broadcast stations. For example, next to a tower in Kaimuki having one FM station and three AM stations, the maximum AM magnetic field was 9 A/m, the square of which is about 32 times higher than the 1982 ANSI standard for the frequency range 0.3-3 MHz. Whether transient or intermittent exposure to such AM-RFR levels would be harmful is subject to debate. In most areas accessible by the general public, the RFR levels were within the 1982 ANSI standard. Since then, however, the use of wireless communications in a growing variety of applications has continued to explode, a trend likely to be maintained during the 1990s. At present, there appears to be little information on current levels of exposure of the general public to RFR.

2 EPIDEMIOLOGIC/OCCUPATIONAL STUDIES

2.1 INTRODUCTION

Most of the evidence on biological effects of RFR is based on results of experiments in which mammals of various species (including human volunteers) and nonmammals such as birds, insects, and bacteria or other microorganisms were exposed to RFR, and specific biological effects and/or endpoints were sought. Also studied were tissues such as excised organs and neurons kept alive artificially (*in vitro*), blood, single cells, cultures of cells, and subcellular components. Other findings are from epidemiologic studies of various segments of the general public and studies of specific subpopulations presumed to have been exposed to RFR by virtue of their occupations; however, such findings are regarded as indirect or inferential because most often the RFR-exposure levels and their durations could not be assessed with any degree of accuracy. Epidemiologic/occupational studies are considered first.

Epidemiologic studies are those in which investigators seek to elucidate the distributions of death or disease in various human populations, and to describe probable agents and other factors that influence such distributions. Epidemiologic studies are either retrospective or prospective, and they often encompass large populations.

In retrospective studies, distributions of death or various diseases that have already occurred are considered, various possible causative agents are examined, and the levels and durations of exposure to the most likely agents are estimated. In a retrospective "cohort" study, a group of people (cohort) presumed to have been exposed to some agent is compared with another cohort presumed not exposed to that agent. Alternatively, comparisons may be made between groups deemed to have had "high" and "low" exposure (instead of "exposed" and "non-exposed" groups) based on specific criteria, to ascertain whether the assumed difference in exposure levels resulted in statistically significant differences in responses between those groups. In a "case-

control" study, persons (cases) having a specific disease or other adverse medical condition are identified, and each case is matched with one or more individuals (controls) ideally identical to that case in such factors as age, gender, socioeconomic status, and medical history, but not suffering from that medical problem. The two populations are then examined for the presence of one or more possible causative agents for that problem, and are compared for statistically significant differences that can be ascribed to those agents.

In prospective studies, measurements of actual exposure levels to a specific agent and determinations of exposure durations can be made, and the exposed and control populations are followed forward in time to determine the persons adversely affected by that agent. Because the onset of a disease cannot be predicted for individuals, case-control studies are retrospective and cannot be prospective. Prospective cohort studies are necessarily lengthy (some may extend for decades) and expensive; usually they are undertaken only when the potential for scientific return is deemed worth their high cost. Thus, most epidemiologic studies are retrospective.

Finding a statistically significant association between exposure to an agent and the occurrence of a disease, although suggestive of a cause-effect relationship, is not sufficient evidence to prove such a relationship. The association may be spurious, as for example the high correlation between the wearing of dresses and the incidence of breast cancer. Other criteria must be examined (Hill, 1965), such as:

1. The strength of association--for example, the incidence of lung cancer in smokers versus nonsmokers.

2. Consistency--occurrence of effects in diverse groups; for example, increased lung cancer in smokers of both genders, all age groups, and races.

3. Specificity--for example, mesothelioma in smokers exposed to high levels of asbestos.

4. Temporality--cause preceding effect in time.

5. Biologic plausibility and coherence--a known or potential mechanism that is not in conflict with information about the history and biology of the disease.

6. Biologic gradient--a dose-response relationship between the amount of exposure to the agent and the magnitude of the response.

7. Experimental evidence--animal data that point to the same association.

In studies of occupational exposure to RFR, the values of the exposure parameters and durations often can be ascertained with a reasonable degree of confidence, e.g., in work places where RFR is used for various industrial processes. For exposure of segments of the general population to RFR as a possible deleterious factor, however, exposures (especially the intensity levels and durations) vary widely with time for each individual and are highly variable from person to person. Moreover, when reliable information on the

degree of exposure is not obtainable, people to be included in the "exposed" group are often selected by their occupation, a dubious method, and it is difficult to find a suitable control group that matches an exposed group in all important aspects except exposure to RFR. Nevertheless, the positive findings of well designed and conducted epidemiologic studies can point to the need for more specific research.

For some agents other than RFR, possible effects at very low levels of an agent are often predicted by extrapolating downward the findings at higher levels on the basis of assumptions about a mathematical relationship between the level (or dose) and the strength of the effect. An underlying assumption in some such relationships is that small doses or the effects thereof may be cumulative. However, the existence versus nonexistence of threshold doses or dose rates for various agents above which deleterious effects can be expected to occur has been debated at length. As a practical scientific matter, such thresholds do exist for many substances, as seen by the fact that many natural substances are essential to life at low concentrations and are toxic at higher concentrations.

For RFR, such predictions by extrapolation from high to low levels are open to challenge. There is considerable experimental evidence from animal studies that specific threshold levels must be exceeded to cause various RFR bioeffects. In effect, the RFR energy continuously absorbed at low incident power densities can be dissipated readily and does not accumulate in the body. In a few animal studies, however, repetitive exposures within about 1 hour of one another at levels just below the thresholds for single-exposure effects were reported to be cumulative (because the time interval between successive exposures was shorter than needed by the body to dissipate the effects of each exposure), but those levels were relatively high (SARs above 4 W/kg). By contrast, ingestion of certain chemicals in small quantities over time can accumulate in a body into potentially harmful total doses.

2.2 RFR AND GENERAL HEALTH

Pazderová (1971), in one of the early epidemiologic studies on possible effects of RFR conducted in Eastern Europe, reported results of medical tests carried out in 1969-1970 on 49 male employees (of mean age 31.8 years) and 9 female employees (mean age 33.9 years) of TV transmitter stations throughout Czechoslovakia. The males and females were employed for averages of 7.3 and 6.9 years, respectively, and represented two-thirds of all persons in that country thus employed. The exposure frequencies ranged from 48.5 to 230 MHz, and field intensities (with transmitter operating at maximum power and doors open) were up to 9.2 V/m (0.022 mW/cm^2 free-space equivalent power density), with a mean of 2.9 V/m (0.002 mW/cm^2). The subjects monitored the operation of the transmitters during most of their working shifts; in the remaining periods, they recorded and adjusted instrument readings and performed routine maintenance on the transmitters. The shifts varied in length but averaged 40 hours per week.

During a 5-day confinement period at the Clinic of Occupational Diseases in Prague, the medical histories of the subjects were recorded, with attention also to their social histories and current non-shift-related activities. Each subject was given a complete medical examination that included chest x-rays and EKGs; the female subjects were given gynecologic examinations. The data

collected included pulse rate, blood pressure, and blood-sugar curves (by the Hagedorn-Jensen method); those data were compared with data for corresponding age groups in the general Czechoslovak population. Electrophoresis was used to determine the blood-protein spectra for 54 of the subjects (percentages of total protein; alpha-1, alpha-2, beta-, and gamma globulins; and albumin-globulin ratio). Samples of their venous blood were given complete assays (erythrocyte, platelet, total and differential leukocyte counts; hemoglobin and hematocrit). The results of both sets of tests were compared by t-test with data for a control group of 55 healthy persons of mean age higher by 6 years.

The medical histories of the subjects showed no preponderance of any specific prior disease, which, as the author stated: "in itself excluded the possibility of any correlation between these diseases and exposure, and therefore we did not evaluate them statistically". Four of the men exhibited hypertension. In two of them, the hypertension was of the juvenile type. The third man, 60 years old, had pronounced signs of coronary insufficiency and not readily curable hypertension; the fourth man exhibited an anginal syndrome as well as coronary insufficiency; both of these subjects also had pathologic EKGs. In all four subjects, hypertension had been diagnosed prior to their employment with TV transmitters. For the remaining subjects, the difference in their mean blood pressure and that of the control group was nonsignificant ($p>0.05$) and no pathologic EKGs were found. Blood-sugar level was pathologic only in the 60-year-old subject noted above, who also showed signs of general arteriosclerosis. The gynecologic examinations were pathologic for four of the women subjects, but onset of the ailments preceded their employment and apparently did not impair their fertility.

The blood-protein spectra were tabulated. No significant differences were found between exposed and control groups except for mean total protein, which was significantly higher ($p<0.01$) in the exposed group, and for mean alpha-1 level, which was also significantly higher ($p<0.05$). Regarding the blood assays, mean hemoglobin was barely significantly higher ($p=0.05$) for the exposed men than the control group, but the difference in hematocrit was not significant ($p>0.05$). The mean total leukocyte and lymphocyte counts were significantly higher in the exposed than the control group, but leukocytosis was a concomitant symptom of inflammation of the upper-respiratory or urinary tract in five of the subjects; the differences between the remainder of the exposed group and the controls were nonsignificant.

Also performed were liver tests (total and direct bilirubin, glucose tolerance, SGOT, and SGPT), ESR test, urinalysis and microscopic examination of the sediment. The results were pathologic for one woman who had and was under treatment for chronic liver damage and pronounced hypercholesterolemia.

Neurologic examinations including EEGs were given to 56 of the subjects, with close attention to neurovegetative [autonomic-nervous-system] symptoms (erythema [redness of the skin], Maranyon's syndrome [scoliosis and flatfoot, with ovarian insufficiency], dermographism, changes in acral temperature [at the extremities] and sweating, tremor of the extended fingers, and pulse-rate changes during examination due to emotional causes or respiratory arrhythmia). The neurologic findings of 29 (52%) of the 56 subjects were entirely normal. Various types of abnormalities characterized by the author as unquestionably not related to RFR-exposure were seen in 13 (23%) of the subjects. The 14

remaining subjects (25%) showed abnormalities of a vegetative type: 3 subjects (5%) with histories preceding exposure and 11 (20%) without apparent exogenous or endogenous cause. By comparison, 16 of 57 members (28%) of a control group of the same age exhibited vegetative-type abnormalities. In the EEGs of the exposed group, there were no statistically significant differences in the distribution of the normal, abnormal, and pathologic rhythms as compared with the controls.

Forty-six of the exposed subjects were selected randomly and were given psychiatric examinations. Of these, 19 (41%) had no psychic disorder. On the basis of their symptoms, the remaining 27 persons (58.7%) were classified into four subgroups: 18 subjects (39.1%) with minor neurotic disturbances that did not affect their ability to work or their life style; 2 subjects (4.4%) with aberrant and psychopathic personalities that were tolerated by themselves or their environment; 5 (10.8%) with aberrant and psychopathic personalities with neurotic disturbances; and 2 persons (4.4%) who had records of institutional psychiatric treatment or showed psychotic traits during examination. By chi-square test, comparison of findings for the 46 subjects with those for a 21-member control group of the same age and educational background showed no significant difference between the groups and no correlation of findings with age or length of service.

58? All 67 subjects also completed psychological questionnaires directed toward the detection of neurasthenic symptoms. Neurotic complaints were reported less frequently in the exposed than the control group.

An ophthalmologist examined the eyes of the subjects, including the anterior segment of the eye in focal light, the lens under artificially induced mydriasis [dilatation of the pupil], and the lens refractive power. Intraocular tension was measured in the subjects older than 40 years and the field of vision was checked when indicated. The ophthalmologic results were compared by t-test with those for a control group of 106 healthy persons of mean age 33.1 years. Refractive disorders, including presbyopia [impairment of vision from loss of lens accommodation], were found in 15 subjects. One subject had chronic conjunctivitis and another subject small cataracts. In general, the results were more favorable in the exposed than in the control group, but the difference was not statistically significant.

The author stated: "In the examined subjects we found no sign of damage due to electromagnetic radiation. Among the laboratory test results, the mean plasma protein levels were significantly increased. Even though we do not regard this as pathological, the possibility of its correlation with exposure to electromagnetic radiation cannot be ruled out. The other test results did not differ from those of the control groups."

In a later study, Pazderová et al. (1974) reexamined effects on blood-protein levels of occupational exposure to RFR from transmitters operating in the TV range (60-300 MHz), "SW" range (3-30 MHz), and "MW" range (640-1500 kHz). In the TV range, 51 people were exposed to fields from about 0.5 to 9 V/m (0.0001 to 0.02 mW/cm^2). The mean age of the group was 35.2 years, and their average exposure duration was 10.4 years. In the SW range, 19 people with a mean age of 39.3 years were exposed for an average of 16.8 years to about 66 V/m (1.2 mW/cm^2); in the MW range, 39 people with a mean age of 41.3 years were exposed for 16.8 years to about 55 V/m (0.8 mW/cm^2). A group of 59 workers (35.4 years mean age) served as controls.

The authors noted that the exposed persons in the previous study came from all parts of the country whereas the control group lived in Prague and differed in their living standards, habits, and nutrition from the exposed group. Thus, regarding the present study they stated: "The control group was chosen from the same regions as the exposed persons, and from the same social standard and living conditions. The only difference is that the exposed technicians worked in irregular shifts, while more than half of the people in the control group only worked morning shifts, but we have not found any data in the literature describing any influence of irregular shifts on the blood proteins."

The people in the exposed group were examined primarily to detect and exclude persons with diseases known to influence blood chemistry; blood samples were taken during their work shifts in the transmitting stations. The blood sample of each subject was examined twice in the laboratory (presumably at the Clinic of Occupational Diseases in Prague); the difference in results for the two examinations of any subject did not exceed 1%.

The results showed that the levels of blood proteins and their fractions were within physiologic limits, both the mean and individual values. However, statistically significant differences were found between the mean values for the control and exposed groups: The mean percentages of total blood proteins were higher for the TV, MW, and SW groups than the control group, but only the difference between the MW group and control group was significant ($p<0.05$). The albumino-globulin quotients and the percentages of albumin for the SW and MW groups were significantly lower ($p<0.01$) than for the control group. The alpha-1 globulin percentages for the MW and SW groups were higher ($p<0.01$) relative to the controls, and the beta globulin percentages were higher ($p<0.01$) for all three exposed groups relative to controls, with the greatest elevation for the SW group. The alpha-2 globulins for all three exposed groups were nonsignificantly ($p>0.05$) different from the controls, but gamma globulin was significantly ($p<0.05$) depressed for the TV group and elevated for the MW group.

The authors stated: "Our previous findings confirmed the data from the literature on the existence of blood protein changes in persons and experimental animals exposed to electromagnetic radiation. To our great surprise, the character of the changes diverged from those so far described, as we did not find any elevation of gamma globulin, which is considered to be typical. We are unable to explain this difference, unless we attribute it to the fact that, contrary to our previous investigation, blood was taken directly at the transmitting stations immediately after exposure to electromagnetic fields. This explanation still remains open to discussion. The more pronounced changes in radio technicians might be ascribed to the higher and longer exposures in comparison with TV technicians."

Klimkova-Deutschova (1974) surveyed 530 persons occupationally exposed to RFR in various industries in Czechoslovakia. From those, a sample of 352 workers was selected and analyzed by computer on the basis of 119 parameters, and the sample was divided into the groups listed below:

1. Workers engaged in metal welding, exposed to frequencies ranging from 0.5 MHz to 3.5-32 MHz [levels not indicated].

2. Workers from two steel factories engaged in tempering steel who were exposed to frequencies of 0.45-150 MHz, with a daily exposure of 50-112 V/m (0.66-3.3 mW/cm^2 free-space equivalent power density), and occasionally of 400 V/m (42 mW/cm^2).

3. Welders of plastics: frequency range 12-150 MHz; daily exposure 20-57.7 V/m (0.11-0.88 mW/cm^2).

4. Technicians operating television transmitters [frequencies and levels not indicated].

5. Workers at a radio transmitting station operating at a wide range of frequencies: from 6 MHz to 30 MHz, using a pulsed-field system [pulse characteristics and levels not indicated].

6. Persons exposed to RFR at frequencies ranging from 3 GHz to 30 GHz while working in industry and at research institutes. Measurements of intensity showed permissible levels in some places, but values exceeding the permissible level 10 or more times were found in other places.

7. Persons working on a linear particle accelerator [the frequencies and levels not indicated].

8. A mixed group comprised of the administrative staffs of 2 factories who not directly exposed to nonionizing radiation, some workers who were exposed to frequencies less than 300 MHz, and others with exposures to frequencies of 300 to 800 MHz [levels not indicated].

The general conclusions of the author are quoted below:

(1) Confirmation that disturbances of the nervous system may be divided into three main stages: (a) the neurasthenic syndrome with autonomic disorders; (b) pseudoneurasthenia with similar subjective complaints, but with microsymptoms of an organic nature, especially in motor systems; and (c) very rare cases of encephalopathy.

(2) The occurrence of contralateral responses to cerebellar [pyramidal] and extrapyramidal disturbances facilitates the detection of early signs of extrapyramidal syndromes, which are identical with those caused by cerebellar irritation.

(3) The predominance of fatigue in certain of the exposed groups was paralleled by a reduction in vigilance, as noted in the EEG recordings and in earlier studies of higher nervous functions.

(4) The occurrence of synchronized EEG activity, with slow rhythms of high amplitude similar to those seen in epileptic seizures, taken in conjunction with the clinical and biochemical findings, permits the conclusion that the involvement of the nervous system is localized in the mesodiencephalic region. Such activity is seen in persons subjected to high levels of exposure, particularly in the form of a pulsed field.

(5) Possible explanations of the pathophysiology include direct penetration of the radiation into the midline structures and the thermal effect in the cisterna magna, which would explain the rare cases of

arachnitis of the posterior fossae and the cerebellar phenomena. The rectangular branching of the blood vessels of the temporal and basal ganglia explains the slowing of the blood stream in these parts of the brain, accompanied by reduced oxygenation. It may be assumed that the subclinical paroxysmal activity is induced by alkalosis resulting from these disturbances.

(6) The nonthermal effects and reversible neurotic manifestations may be attributed to the interruption of synaptic transmission and to changes in reflex activity under enzymatic influences.

The specific findings included EEG disorders (consisting of synchronized waves of high amplitude and slow rhythm) and biochemical changes (such as elevation of fasting blood glucose, serum beta-lipoprotein, and cholesterol). The changes in the brain-wave patterns and in the blood sugar, protein, and cholesterol levels were described as more pronounced in the people exposed in the range 3-30 GHz.

The author noted: "By making an exact evaluation of the extent of the disturbances, we were able to estimate that most of our patients had suffered less serious injury than had some other groups working with chemical noxious agents...A special feature of our results lies in the fact that when the investigations were started preventive measures were not strictly observed and less attention was paid to the hazards than is the case today. Nowadays, strict hygienic supervision of working places prevents the development of serious organic injury."

In presenting the results of this study, the author indicated when the differences among the groups for specific manifestations were statistically significant at the 5% or 1% level, or were not significant. However, no numerical data and statistical treatment thereof were given, rendering it difficult to evaluate the findings or accept them at face value.

Kalyada et al. (1974) reviewed the results of prior studies (mostly their own), in which they clinically examined a group of specialists (number not given) under 40 years old in the USSR exposed to "non-thermal intensity within the range 40-200 MHz" by working with RFR generators for 1 to 9 years. The authors found no organic lesions, but noted the frequent occurrence of functional changes in the central nervous system (52%), the principal form of which was described as "vegetative dysfunction accompanied by neurasthenic symptoms". They remarked that the relationship between the frequency of neurodynamic disturbances and duration of work was clear-cut.

Several of the manifestations were biphasic. Specifically, for those employed for up to 1 year, the level of thermal-receptor activity was higher (about 160% of control level), and the temperature-sensitivity threshold and threshold excitability of the visual analyzer were both lower (80% and 50% of the respective control levels). By contrast, for those employed for 3 to 9 years, the level of thermal-receptor activity was lower (about 60% of control level) and the temperature-sensitivity threshold and threshold excitability of the visual analyzer were both somewhat higher (110% and 120% of the respective control levels.) Among the specific changes reported were deviations in the physicochemical and functional properties of erythrocytes and leukocytes, including lower osmotic resistance of leukocytes and lower phagocytic reaction that led to weakened immunobiological reactivity.

The authors also stated: "Experimental data obtained in volunteers under laboratory conditions of irradiation mimicking industrial variants revealed certain principles concerning general physiologic responses of the human body towards electromagnetic fields. The thermoregulatory system, some systems of hemodynamics and thermal, optical and auditory analysers proved most functionally reactive and sensitive to the influence of experimental irradiation. The dynamics of functional deviations were compared with those accompanying the presumed action of the factor. The irradiation was systematic with daily 15 min exposures and the 30 days' duration of each series of treatments. The ambient temperature ranged from 22.6 to 23.4 °C with relative humidity of 40-46%. The results showed that some functional deviations took place during irradiation, while others followed it. The skin temperature of distal parts of the body (hands, feet) was elevated during the whole period of actual irradiation with simultaneous intensification of heat loss through emission and demobilization of heat receptors. The number of active cold receptors sharply increased."

No RFR intensity values were presented for either the specialists or the volunteers. Most of the findings were described in narrative form, with no actual data cited. Bar graphs showing changes, relative to controls, of a few specific parameters with exposure duration were given, such as the biphasic manifestations mentioned above, but the control group used for comparison was not described. Moreover, statistical treatment of the results was not given. Consequently, this paper yielded little if any basis for affirming or denying the occurrence of adverse effects of occupational or laboratory exposure of humans to RFR. [Adequate translations of the papers on prior studies cited by the authors, e.g., Kalyada and Nikitina (1983a) and Kalyada et al. (1983b, c), were not available.]

Sadčikova (1974) presented clinical observations on the health status of two groups of USSR workers engaged in the regulation, tuning, and testing of diverse equipments emitting RFR at unspecified "microwave" frequencies. Both groups were comparable with respect to sex and age, but differed in intensity of exposure and duration of work. The workers in the first group (1000) were exposed at levels up to a few mW/cm². Those in the second group (180) were exposed to values rarely exceeding several hundredths of a mW/cm², but exposures to higher levels could have occurred during extremely short periods. Young men with lengthy histories of employment (5-15 years) with microwave sources predominated in both groups. Some nervous tension during work could not be excluded. A group of 200 people matched with respect to sex, age, and character of work processes that did not involve RFR-exposure served as controls.

Reported in the form of bar graphs with standard-error bars for each group were the percentage changes in 16 symptoms: 5 "neurologic" symptoms (head heaviness, tiredness, irritability, sleepiness, and partial loss of memory); 6 "autonomic-vascular" symptoms (inhibited dermographism, expressed dermographism, hyperhidrosis, bradycardia based on pulse rate, arterial hypotension, and arterial hypertension); and 5 "cardiac" symptoms (cardiac pain, dullness of the heart sounds, systolic murmur, bradycardia by EKG, and lowering of deflections T-I and T-II).

For the higher-RFR group, the percentage changes were larger than for the control group for all symptoms except arterial hypertension, which was

about the same. All of the percentages for the lower-RFR group were also higher than for the control group, except for arterial hypotension, which again was about the same. For 11 of the 16 symptoms, however, the percentage changes were larger for the lower-RFR group than the higher-RFR group. The authors did not provide statistical analyses of these results, but from the standard-error bars shown, some of the differences between each RFR group and the control group and between the two RFR groups appeared to be significant. However, it is difficult to ascribe the differences to RFR-exposure.

Eye examinations with the slit lamp revealed some lens opacities, mainly in the cortical layer and in superficial layers of the mature nucleus along its equator; only single opacities were found in the center. The numbers of opacities for the RFR groups did not exceed control values. However, the opacities progressed with increasing duration of exposure. A few subjects of the higher-RFR group said to have worked under not specified "unfavorable" conditions had developed cataracts. It seems likely that these persons had been exposed to RFR levels well in excess of the cataractogenesis threshold found in animal studies.

The authors described the "asthenic syndrome" in detail, based on prior work as well as the results in this paper. The progression of "microwave sickness" in 100 cases was described in a table in the paper, the text of which predicted little chance for recovery without patient removal from the work environment. However, symptomatology similar to the asthenic syndrome or to microwave sickness has not been reported in Western RFR-bioeffects studies, so it is difficult to accept these Eastern European findings at face value. Also of concern regarding these studies is that they were not conducted with the investigators "blinded" to the exposure histories of the patients. Thus, the role of investigator bias cannot be excluded.

Siekierzynski (1974) examined the health status and fitness for work of 841 men in Poland of ages 20 to 45 years who had been occupationally exposed to pulsed RFR "of various frequencies within the whole range used in radar operations" (other characteristics not specified). The exposures were during working hours for 2 to 16 years, depending on age. (By regression analysis, a high degree of correlation between age and duration of employment was found). Of these, 507 men were exposed at average power densities exceeding 0.2 mW/cm^2 (group I). Those men "worked both in closed rooms and in the open, observing typical individual protective measures according to the regulations of work safety and hygiene existing in this country". The remaining 334 men (group II) were exposed at the same installations to no more than 0.2 mW/cm^2. The author noted that low-exposure group II was selected for comparison because it was difficult to find an unexposed group who worked under otherwise similarly specialized conditions. However, the hygienic factors: the type and intensity of various stress factors, changes in circadian cycle, the noise intensity, the temperature and humidity of the rooms, etc., were comparable for the two groups.

All examinations were performed in the same clinic; the tests included ophthalmoscopy by slit lamp, and neurologic checkups supplemented with psychological tests and EEG recordings. After clinical observation and possible treatment were completed, a decision was rendered for each person regarding his fitness for further work in RFR environments. The author noted that only data for the most frequent problems were presented in this paper.

The numbers of persons in each group were tabulated with regard to: (1) fitness for work in four categories (able to work or unfit because of ophthalmic, functional, or "other" disorders); (2) incidence of functional disorders in four categories (none, neurosis, gastrointestinal disorder, abnormal EKG); and (3) lens translucency (graded as 1, 2, or 3 degrees).

The mean percentages and standard deviations of the occurrence for each fitness characteristic, functional disorder, and lens translucency in each group were determined, and their correlations with employment duration and age were analyzed by Student's t-test and Fisher's F-test, with 5% taken as the significance level. The results of those analyses were presented in a set of tables. For both groups, there was no significant correlation between the causes of unfitness for work and employment duration. Found within each group, however, was a significant correlation between lens translucency and age. Also significant was a significant correlation between lens translucency and duration of employment, but only for group I, which had the most exposure to pulsed RFR.

In summary of this paper, the findings were negative with regard to the effects of occupational exposure to RFR on the health status of either group. Additional details regarding specific aspects of this study were presented in three other papers: Czerski et al. (1974a), Siekierzynski et al. (1974a, b). Indicated in Siekierzynski et al. (1974a) was that the highest exposure level of group I was 6 mW/cm^2 "...during short periods of time, according to Polish rules about safe exposure".

Robinette and Silverman (1977) selected 19,965 men (mostly white) with service in the Navy during the Korean War who, from their titles (Electronics Technician, Fire Control Technician, or Aircraft Electronics Technician), were regarded as electronic-equipment-repair technicians and therefore were assumed to have had significant occupational exposure to RFR. Selected as a control group were 20,726 Naval men considered electronic-equipment operators (titles: Radioman, Radarman, or Aircraft Electrician's Mate) and thus were presumed to have had little occupational exposure to RFR. The mean age of the control group was about 1.5 years lower than the exposed group. The authors compared the extant records of the two groups on mortality for 1955-1974, in-service morbidity for 1950-1959, morbidity for 1963-1976 in Veterans Administration hospitals, and requests for disability compensation granted or disallowed.

Only the mortality results were presented in this paper. There were 619 deaths (3.1%) from all causes in the exposed group versus 579 deaths (2.8%) in the control group, a statistically nonsignificant difference. The authors noted that the death rates of both groups were lower than for the comparable age-specific white males (937 and 916) in the U.S. population at large.

Those decedent data showed no significant difference between exposed and control groups in the deaths from all disease, respectively 311 (1.6%) and 321 (1.5%), both significantly lower than for the corresponding groups in the age-specific white male population. The deaths from disease were categorized as follows: all malignant neoplasms; cardiovascular (including vascular lesions of the central nervous system [strokes], and arteriosclerotic heart); chronic nephritis, other renal; influenza and pneumonia; and cirrhosis of the liver. In all of these categories, the total numbers of deaths were smaller than in the U.S. age-specific white male population. Also, none of the differences in

total numbers between the exposed and control groups was significant, but the numbers of deaths associated specifically with arteriosclerotic heart disease were significantly lower ($p<0.05$) in the exposed than in the control group: 8 (0.04%) versus 26 (0.13%). The mortalities from cancer were also divided into various categories, but there were no significant differences between exposed and control groups.

However, the death rate from trauma was significantly higher ($p<0.01$) in the exposed than in the control group, 295 (1.5%) versus 247 (1.2%). When the deaths from trauma were subdivided into motor-vehicle accidents, "other accidents", suicide, and homicide, the only significant difference ($p<0.01$) between the exposed and control groups was in the "other-accident" category, 130 (0.65%) versus 70 (0.34%) deaths. In that category, however, the death certificates and the other mortality data about the men in the exposed group showed that many had died in military-aircraft accidents after the Korean War, presumably because more of them later became flying officers (5.3% versus 2.3%). Thus, the authors found no statistical association between adverse health effects and presumed RFR exposure.

Silverman (1979), in a review of RFR-epidemiologic studies, included the one above of Naval personnel (with the two groups called "high-exposure" and "low-exposure" and with 144 and 55 additional men, respectively). The author remarked: "There have been enough accidental exposures at estimated levels exceeding 100 mW/cm² to indicate that there are occupations in which some men at some times on certain classes of ships have been exposed well in excess of the [ANSI (1974)] 10 mW/cm² limit [citing Glaser and Heimer, 1971]." Also noted by the author: "Shipboard monitoring programs in the Navy since 1957 show that men in other occupations rarely, if ever, were exposed to doses in excess of this limit. Radiomen and radar operators (our low-exposure group), whose duties keep them far from radar pulse generators and antennae, were generally exposed to levels well below 1 mW/cm², whereas gunfire control technicians and electronics technicians (our high-exposure group) were exposed to higher levels in the course of their duties."

In addition to assessing occupation, the author used individual records to determine the length of time in the occupation, the class of ship, and the power of the equipment on the ship at the time of exposure; however, because of cost and time considerations, these determinations were done only for the men in the high-exposure occupations who had died from nonaccidental causes, and for a randomly selected 5% sample of living men in the same occupations. From this information, an index of potential RFR-exposure called the "Hazard Number" was constructed for each man, defined as the product of the number of months of assignment to a ship or aircraft with the sum of the power ratings of all the gunfire-control radars aboard that ship or of all the search radars aboard that aircraft.

The percentages of men with high values of Hazard Number were much larger for the occcupations Fire Control Technician and Aircraft Electronics Technician than for Electronics Technician. However, the author did not present comparisons of mortality data among them.

Silverman (1979) concluded: "Differential health risks associated with potential occupational exposure to radar in the Navy more than 20 years ago are not apparent with respect to long-term mortality patterns or hospitalized

illness around the period of exposure, two endpoints for which there is virtually complete information for the total study group. Later hospitalization (in Veterans Administration facilities only) and awards for service-connected disability, the two other endpoints examined, provide incomplete information. While some significant differences among the occupational groups classified by level of potential exposure have been found with respect to all endpoints studied, the differences could not be interpreted as a direct result of microwave exposure."

Morbidity data and other health-related aspects were not presented in either paper, but Silverman (1979) did note the possibility that effects involving the cardiovascular, endocrine, and central nervous systems may be transient and may disappear shortly after termination of exposure or not produce symptoms that warrant hospitalization.

The information above was also presented in Robinette et al. (1980). In addition, the numbers of admissions to Naval hospitals during the period 1952-1959 (except for 1955, for which the files were not available), and admission rates (per 1000 per year) for men in the low-exposure and high-exposure groups were tabulated by diagnosis (per International Classification of Diseases). Of 18 comparisons between groups, only two were significant: The low-exposure group had significantly higher admission rates for mental disease ($p<0.001$) and for accidents, poisonings, and violence ($p<0.01$) than the high-exposure group. For no disease class was the admission rate of the high-exposure group significantly higher than of the low-exposure group.

Data were also obtained for numbers and rates of admission to Veterans Administration (VA) hospitals during 1963-1976, but it was evident that the admissions to VA hospitals comprised only small fractions of hospital care of these veterans, which precluded drawing any firm conclusions. Also examined were the numbers and rates (per thousand) of men who received VA compensation in December 1976 by diagnosis and exposure class. The only significant difference ($p<0.01$) was for mental conditions, 7.1 per thousand for the low-exposure group versus 4.8 per thousand for the high-exposure group.

In a letter, Morton (1981) questioned the basis used for selecting the high-exposure and low-exposure groups, stating: "Is it possible that no suitable controls existed among personnel assigned to shipboard duty?" In response, Robinette (1981) noted: "A search for men of similar educational attainment, aptitude for technical work, and training by the Navy in their occupation, led to the selection of the equipment operators as members of the potential low-exposure cohort. The duties of these men required, for the most part, that they be below decks in areas where equipment was not being repaired and which were not traversed by operating radars."

Forman et al. (1982) reported on the accidental overexposure to RFR of two men who had been operating a portable high-power microwave radar tracking system while on military field maneuvers. They had been exposed on successive days while facing a circular-aperture antenna emitting X-band CW RFR and were in its near field. From calculations and follow-up field survey, the electric field strength was in the range 475-580 V/m, corresponding to an equivalent plane-wave power-density range of 60-90 mW/cm^2, with a range specified because of uncertainty about the distances of the men from the antenna. The most probable electric field strength was about 580 V/m (equivalent to 90 mW/cm^2).

During exposure, the men were lightly clothed in military fatigue uniforms and hats. The ambient temperature was about 18 °C and the relative humidity was about 50%.

One of the men was 54 years old and in good health. He had been exposed continuously for 80 seconds. At that time, he reported severe chest pain, vertigo, and a heating sensation of the chest and head. Facial redness of the skin persisted for three days. Stomach cramps after eating, difficulty in swallowing, shoulder soreness, and gritty eye sensations occurred within the first day and persisted for several weeks. He also recurrently experienced rapid onset of severe headaches, with some headaches preceded by scintillating areas of depressed vision, and he suffered from insomnia, irritability, and emotional lability. His psychological symptoms led to disruption of work and family life. The severity of the subjective complaints peaked three months after the incident, coincident with a diagnosis of arterial hypertension.

Five months after the incident, the man was given extensive medical, ophthalmologic, endocrine, and psychiatric evaluations. No secondary cause of hypertension was found, nor were there any lenticular opacities. Neurologic results were normal, and various psychological tests showed no evidence of organicity. Blood pressure was brought down with medication and remained within the normal range after medication withdrawal. Thus, the diagnosis was acute post-traumatic stress disorder.

The other case was a 21-year-old healthy man who had been intermittently exposed to the RFR over a five-minute period for a total of about 75 seconds. The subject immediately felt a heating sensation in his chest and head and a headache. He reported facial skin redness that lasted for a day. Creatine phosphokinase was found to be elevated two days later, but subsided within 72 hours. The subject reported non-disabling irritability, insomnia, headaches, photophobia, and visual blurring. Hypertension was seen four months after the incident. An extensive medical examination revealed no organic cause for the hypertension, visual disturbances, or psychological complaints. Psychiatric interviews and psychological testing yielded inconsistent results. As for the first subject, the diagnosis was acute post-traumatic stress disorder.

The authors mentioned that two other healthy men, aged 30 and 39 years, had been exposed to the same RFR at about the same time, but for 5-10 seconds. Both men reported immediate symptoms similar to those of the subjects above, but neither had long-term pathologic symptoms or signs. The authors mentioned reports from Eastern European countries about occurrence of the "neurasthenic syndrome" from chronic RFR-exposure, with onset symptoms resembling those above, but noted that the existence of neurasthenic syndrome or "microwave radiation sickness" is widely discounted in Western countries. Moreover, the RFR levels for the cases above were quite high.

Djordjević et al. (1979) did a clinical study of 322 radar workers aged 25-40 years who had been occupationally exposed for 5 to 10 years to pulsed microwaves of various frequencies (characteristics not given) used in radar operations in Yugoslavia. On the basis of power-density measurements with PO-1 (USSR) apparatus and a USA Narda B86B3? [sic] monitor, the workers were generally exposed to less than 5 mW/cm². For comparison, 220 persons matched in age, character of working conditions, and social and living conditions, comprised the control group. The clinical examinations included detailed internal, neurologic, ophthalmologic, otologic, hematologic, and biochemical tests.

The numbers and percentages of exposed and control subjects diagnosed for various ailments were tabulated; the most prevalent diagnosis was for "Neurocirculatory Asthenia" in 49 (15.2%, not 15.5% as shown) of the exposed subjects and 29 (13.2%) of the control subjects, a difference stated to be nonsignificant (no SEs given). For "Upper Respiratory Infection," the next most prevalent diagnosis, the percentage was lower in the exposed than the control group: respectively 9.9% versus 14.1%.

The subjective complaints of headache, fatigue, and irritability were more frequent in the exposed group, but sleep disturbance, inhibition of sexual activity, and memory impairment were comparable in the two groups. Tabulation of the means and SEs of the various segments of the EKGs showed no significant differences between the groups. Also, no significant differences between the groups were seen in the mean counts of peripheral neutrophils, lymphocytes, eosinophyls, monocytes, and thrombocytes [platelets], as well as in the various hematologic and biochemical assays done. The authors concluded that prolonged occupational exposure to microwaves did not affect the health status of the radar workers, and that their subjective complaints may be attributed to the specific occupational factors at the radar stations, such as noise, peculiar lighting, inadequate ventilation, and attention to the radar screen.

In Djordjević et al. (1983), the results of a 15-year clinical study of a group of 500 workers occupationally exposed to RFR in the centimeter-wave band at levels usually less than 5 mW/cm² for about 2 hours daily in the near-field and far-field regions of high-power radar(s) were compared with those for 350 controls for the years 1970, 1975, and 1980. Unclear is whether those results included some or all of the data from the Djordjević et al. (1979) study discussed above; the list of diagnostic terms tabulated in the later paper differed in some items from those in the earlier paper. Most prevalent in the later paper was the diagnosis "Neurovegetative Dystonia," reported respectively in 17% of the exposed group versus 20% in the control group for 1970; in 12% versus 8.8% for 1975; and in 15% versus 10% for 1980. The authors noted that the respective differences were not significant, but did not present any statistical treatment of those human data.

The absence of statistical treatment diminishes the credibility of the negative findings of the two studies above. Also, neither "Neurocirculatory Asthenia" nor "Neurovegetative Dystonia," the major diagnoses therein, are disorders recognized in Western medicine.

Also discussed briefly in this paper were findings of their experimental investigations with animals exposed to 2.45-GHz RFR at levels ranging from 5 to 200 mW/cm² for various durations. The effects reported, notably cataracts in the rabbit eye and testicular damage in the rat, were ascribed by the authors to RFR hyperthermia.

The U.S. Embassy in Moscow was irradiated with RFR from 1953, the year after the United States Government moved its chancery to Chekovsky Street, until February 1977 (Pollack, 1979). The presence of RFR had been detected intermittently before 1962 during routine surveillance of the building; continuous monitoring of the signals was instituted during that year.

Details about the signal frequencies, characteristics, irradiation durations, and average power densities (or equivalent field intensities) at various locations within and on the roof of the chancery were presented in a report by the U.S. Department of Commerce's National Telecommunications and Information Administration (NTIA, 1981). The signals consisted of up to 7 noise bands, each a few MHz wide, in the frequency range from 0.5 to 10 GHz, with maximum amplitudes in the 2-3 GHz range. The incident average power densities and exposure durations varied with the period: 5 $\mu W/cm^2$ for 9 hours per day at inception in 1953, 15 $\mu W/cm^2$ for 18 hours per day from June 1975 to 7 February 1976, and less than 1 $\mu W/cm^2$ for 18 hours per day thereafter.

Within rooms having windows or doors in outside walls toward the RFR sources, typical levels were about 4 $\mu W/cm^2$ within 2 feet of a door or window and 2.5 $\mu W/cm^2$ elsewhere therein. The highest level was 24 $\mu W/cm^2$, found in one room during a 2-hour period of unusual signal strength on 24 January 1976. It is noteworthy that this level was found in only one part of the embassy, so the exposure levels of most of the embassy personnel for most of the time were probably well below the maximum permissible level (5 $\mu W/cm^2$) specified in the then USSR standard for exposure of the general population.

Lilienfeld et al. (1978) conducted a study of the health of the U.S. personnel assigned to the Moscow embassy during the period from 1953 to 1976. The authors, after expending considerable efforts in tracing employees and dependents, identified 1,827 employees and 1,228 dependents as having been at the Moscow embassy during that period. The control population consisted of 2,561 employees and 2,072 dependents who had been assigned to the embassies and consulates in Budapest, Leningrad, Prague, Warsaw, Belgrade, Bucharest, Sofia, and Zagreb during the same period. Periodic tests for RFR at those control sites showed only background levels.

Medical records were reviewed for 1,209 of the Moscow employees and 834 of their dependents. The control group comprised 1,882 employees and 1,507 dependents. Health questionnaires were returned by 969 Moscow employees and 1,129 control employees. The number of health questionnaires obtained from the dependents was not clearly indicated in the report.

The authors recognized and commented on the limitations of this study due to their inability to acquire complete sets of medical records, death certificates, and returned health questionnaires, and to the imprecision in classifying individual employees on their probable extent of RFR exposure. They also noted that for many of the medical conditions studied, the sizes of the study populations were too small for detecting less than twofold excess risks. In addition, they indicated that the highest RFR levels were recorded late in the period of irradiation and therefore, for the subgroup with the highest potential exposure, the time period during which health effects might have become apparent was the shortest. However, despite these acknowledged limitations, the authors were able to draw the following conclusions:

No discernible differences were found between the Moscow and control groups in total mortality or mortality from specific causes, nor were there mortality differences between the Moscow and control groups of dependent children or adults. The mortality rates for the Moscow and control groups were lower than for the U.S. population at large, except for cancer-related deaths, which were fractionally higher among Moscow-female employees (8 of 11

deaths) than control-female employees (14 of 31 deaths). The authors stated: "It is difficult to attach any significance to the relative proportion of cancer deaths in females because of the small numbers of deaths involved."

The data from the questionnaires showed higher incidences of several health problems in the Moscow employee groups than in the controls: more refractive eye problems that were correctable; more psoriasis cases in the men; more anemia cases in the women; and more frequent cases of depression, irritability, difficulty in concentrating, and memory loss. The authors noted:

"In view of the possibilities which had been publicized of the increased danger to their health and that of their children, it is not at all surprising that the Moscow group might have had an increase in symptoms such as those reported. However, no relationship was found between the occurrence of these symptoms and exposure to microwaves; in fact, the four symptoms mentioned earlier, which showed the strongest differences between the Moscow and Comparison groups, were all found to have occurred most frequently in the group with the least exposure to microwaves."

For dependents, the authors found no significant differences between the adults in the Moscow and control groups. The incidence of mumps in Moscow-based dependent children was twice that in control children. The incidences of congenital anomalies in children born after the arrival of the parents at their duty stations were comparable for the Moscow and control groups. The authors concluded:

"With very few exceptions, an exhaustive comparison of the health status of the State and non-State Department employees who had served in Moscow with those who had served in other Eastern European posts during the same period of time revealed no differences in health status as indicated by their mortality experience and a variety of morbidity measures. No convincing evidence was discovered that would directly implicate the exposure to microwave radiation experienced by the employees at the Moscow embassy in the causation of any adverse health effects as of the time of this analysis."

Hamburger et al. (1983) noted that physical therapists are known to use various diathermy modalities (which the authors characterized as "microwave, shortwave, infrared, and ultrasound equipment") during treatments of patients. The authors therefore endeavored to determine whether such therapists might be having adverse health effects from exposures to the emissions from such units on a dose-related basis. Toward that end, they analyzed the responses from male members of the American Physical Therapy Association (APTA) to a mailed questionnaire. The only consistent statistically significant finding was an apparent association between the occurrence of heart disease and exposure to "shortwave" radiation, as discussed below.

Although the authors considered other factors in the questionnaire, they emphasized those health experiences reported in the RFR-bioeffects literature as being associated with exposure to low RFR levels. The responses requested from each subject included the occupational history of diathermy utilization by length of employment in each position held since entering that clinical affiliation, and the number of treatments of each modality administered per typical work week. The responses indicated that for the operators younger

than 35 years, the mean time spent within 3 feet of the equipment was 2.4 minutes per treatment with microwave diathermy and 2.7 minutes per treatment with shortwave diathermy. (Therapists initiate a treatment and usually then leave to attend other matters for the remainder of the treatment.) Among the other factors considered were the frequency of patient treatments, the years of work experience, and use of infrared and ultrasound diathermy.

The authors also cited a survey, conducted by Ruggera (1980), of three microwave (2.45-GHz) and six shortwave (27-MHz) diathermy units at sites in 6 health facilities. The results of the survey were expressed as the means and ranges of free-space-equivalent power densities 1 meter from the units at eye and waist levels of an operator. For the 2.45-GHz units, the measurements yielded a mean of 0.65 mW/cm² and a range of 0.08-1.30 mW/cm² at eye level, and 0.71 mW/cm² and 0.08-1.20 mW/cm² at the waist. For the 27-MHz units, the mean and range of free-space-equivalent power densities for the magnetic component were 1.06 and 0.09-4.11 mW/cm² at eye level, and 2.49 and 0.09-8.32 mW/cm² at waist level; the corresponding values for the electric component were 1.21 and 0.06-5.19 mW/cm² at eye level, and 4.05 and 0.04-16.58 mW/cm² at the waist.

Hamburger et al. (1983) did three mailings of questionnaires, to reduce the total number of nonresponses. The final population sample consisted of 3,004 respondents from a total of 5,187 therapists solicited. Respondents were divided into subgroups according to exposure across and within the energies of the four modalities above. The diathermy modalities were coded as U (ultrasound), I (infrared), M (microwave), and S (shortwave). Initially, the population was distributed by the authors among the 15 exposure subgroups consisting of those exposed solely to each modality and those exposed to all possible combinations thereof, plus an unexposed control group. However, the small sizes of several of the groups led the authors to merge those into other groups to obtain more meaningful statistical results, thereby obtaining the following 9 subgroups and the numbers of therapists in each: U=208, MU=116, SU=512, IU=64, MSU=390, ISU=429, IMSU=1097, other=67, and none=121.

Because cumulative exposure and the incidence of specific pathologic, psychologic, and physiologic processes are usually related to age, the authors divided each subgroup above into those younger than 35 and those 35 or older (35+), and further stratified the 35+ group into the three subgroups 35-44, 45-54, and 55+. Subgroups were also dichotomized into high-exposure and low-exposure categories by using mean duration of employment (<14 years and 14+ years), mean frequency of treatments administered (<17 and 17+ per week), and jointly by employment duration and treatment frequency.

Before analyzing for possible effects of microwave and/or shortwave RFR, the hypothesis that ultrasound alone does not contribute to potential effects was tested for those in the high-exposure, 35+ age group by comparing those of this age category in the U subgroup with those in the "none" subgroup, on the assumption that a negative finding would apply to the younger, less-exposed groups as well. There were no statistically significant differences between the U subgroups for any of the health effects considered. This hypothesis also was tested for infrared only by comparing the SU and ISU groups (the I group being too small for this purpose). Again, no significant differences were found.

Tabulated for the nine coded exposure subgroups above were selected characteristics of the respondents (age, race, marital status, present work setting, personal therapy with any modality, x-ray exposures) and prevalence among them of the following reported conditions: blood disorder, cataracts, diabetes, endocrine disorder, hearing disorder, heart disease, high and low blood pressure, nervous breakdown, and "other".

The authors noted that the prevalence of conditions were higher for the respondents in the 35+ age group relative to the total of all respondents, but found that the prevalence rates for the entire cohort in all instances were below the rates for the general population and that no single subgroup showed markedly higher rates relative to total rates. However, they indicated that the all-four-modalities (IMSU) subgroup showed significantly higher rates for heart disease than those for the other subgroups. The authors then formed new subgroups: "microwave, shortwave, and joint microwave/shortwave exposure," and further divided them into high-exposure and low-exposure groups. A respondent with any exposure to microwaves was included in the microwave group. Similar definitions were used for shortwave and joint exposure, so the subgroups were not mutually exclusive and resulted in double-counting of some subjects, a point recognized by the authors. They concluded:

"Despite the fact that the heart disease rate appears higher among the microwave exposed than the shortwave exposed, a test of the microwave subgroup against the remainder of the cohort showed no statistically significant difference. In fact, the only subgroup where heart disease rates were significantly higher than the remaining total was the IMSU subgroup. Most rates for specific subgroups which exceed the total rates are based on small sample size and therefore are thought not to be real increases."

The authors constructed contingency tables for the three types of exposure (microwave only, shortwave only, and joint microwave/shortwave) and for the three high-exposure versus low-exposure situations (frequency of treatment, length of employment, and the combination thereof). They thereby derived 3x3 contingency tables for each of the 10 medical conditions, for a total of 90 contingency tables. They also calculated the odds ratios for high-exposure versus low-exposure in the three exposure categories for each contingency table, and determined the confidence intervals for the odds ratios that were statistically significant after adjustment for age.

The values in each table were tested with the Mantel-Haenszel chi-square test for homogeneity. Some significant results were obtained. Most of those results, however, became nonsignificant when age groups were combined by the Mantel-Haenszel method (stratification by age group), which permits correction for age-related effects. Heart disease was the only condition that remained statistically significant, and then only in 4 of the 9 type-of-exposure versus high-low situations: microwave x frequency of treatments per week, shortwave x combined frequency of treatments per week, duration of employment, and joint microwave/shortwave x frequency of treatments a week. The other 5 situations were not significant ($p>0.05$); specifically: in all 3 cases where duration of employment alone was a criterion of high exposure versus low exposure, in the case for joint microwave/shortwave exposure x combined treatment frequency and employment duration, and in the case for microwave exposure x combined treatment frequency and employment duration.

It is noteworthy that of the 90 contingency tables, only the 4 above showed significance at the 5% level, a finding that is no better than chance. None of the other 9 medical conditions was statistically significant, nor was the incidence of neoplasms. Also assessed were possible confounding effects of diagnostic X-ray and diathermy treatments on individual respondents. After adjustment for age, no conditions related to such treatments were found to be statistically significant.

The single finding above may be cited by some as "proof" that exposure to microwave/shortwave RFR causes heart disease. However, careful analysis of the paper did not yield convincing evidence that this is so. First, the paper illustrated the problems associated with endeavors to uncover possible causal relationships between a purported health-effects agent (RFR in this case) and medical conditions in an identified population by using only the responses to a mailed, self-administered questionnaire. The rate of responses was 58%, so 2,183 persons did not respond. The authors did not mention any attempt to reach nonrespondents by telephone or in person, to try to characterize them as a group. (Statistical techniques exist to correct for possible bias when the nonrespondents group is large.) Moreover, probably many of the 58% that did respond were self-selected in the sense that they may have responded because they had medical conditions and were curious about how such conditions may have arisen.

That sole significant finding is weak at best. The link between heart disease and one aspect of occupational exposure was based on the self-reported recollection of the frequency or number of treatments per week with shortwave radiation. However, the absence of such a link for joint shortwave/microwave exposure was downplayed. If the results are interpreted to mean that exposure to shortwave radiation is a causal agent but that joint shortwave/microwave exposure is not, it also could be inferred that microwave exposure protects against possible adverse effects of shortwave exposure with respect to heart disease, a most unlikely conclusion. In addition, duration of employment, which normally would be considered a factor in cumulative exposure, had no statistically significant role.

Last, from the RFR-bioeffects literature, the authors classified heart disease into: (1) disorders of conduction/rhythm and ischemia, and (2) "other". Statistical significance was found only for category (1). However, heart disease comprises many symptoms that have various etiologies. Cigarette smoking, for example, is a known major risk factor and a strong predictor of heart disease in an aging population such as the 35+ age group in this study. For unexplained reasons (but acknowledged by them), the smoking history of the individuals was not requested in the questionnaire. Failure to consider this major biasing factor does not inspire great confidence in the only positive finding of this study.

Burr and Hoiberg (1988) compared the hospitalization rates of 1,063 Naval pilots who primarily flew "electronically modified aircraft" (the test group) with an age-matched control group of 2,126 pilots who flew other types of aircraft. A major difference between the two groups was that the pilots of the test group were presumed to be subjected to greater potential risks from exposure to higher levels of ionizing radiation (from flying at higher altitudes) and to nonionizing radiation (such as from the onboard antennas and electronic equipments) than the control group.

The results showed that in the age range 21-26 years, control pilots had a significantly higher mortality rate for aviation-related injuries and also higher hospitalization rates for accidents, poisonings, and violence than those in the test group. In the age range 27-32 years, the pilots in the control group had a significantly higher hospitalization rate for mental disorders than the test group. However, the authors noted that neither group had any hospitalizations for conditions related to exposure to ionizing or nonionizing radiation.

The possibility that workers in occupations that involve the use of RFR for welding or sealing plastics would be exposed to excessive RFR levels was examined in several studies, among them those by Cox et al. (1982), Bini et al. (1986), and Joyner and Bangay (1986b). Cox et al. (1982) measured the electric and magnetic fields in the frequency range 18-31 MHz at the stations of 82 operators of dielectric heat sealers in 13 U.S. facilities, and found that 55% of those operators were being exposed to levels exceeding the maxima permitted in the OSHA (1978) exposure guidelines [respectively 200 V/m and 0.5 A/m, or 10 mW/cm^2 equivalent plane-wave power density, as in the ANSI (1974) guidelines]. However, Cox et al. (1982) did not discuss any specific health problems of those workers.

Joyner and Bangay (1986b) did a survey of the electric and magnetic fields of 101 dielectric heaters operating at a frequency of 13.56, 27.12, or 40.68 MHz in Australia during 1982 and 1983. Their results showed that 39% of the heaters were exposing the operators to levels that exceeded the Australian guidelines by factors of more than 1 and less than 10, and that the levels of another 23% of the heaters exceeded those guidelines by factors greater than 10. The authors did not discuss possible health effects on the operators of those heaters.

Bini et al. (1986) described measurements of the RFR levels in a room (presumably in Florence, Italy) containing 67 sealers used to make thermal seams in various plastic-sheet articles, such as inflatable boats. Most of the sealers operated at 27.12 MHz, with deviations of several MHz, depending on load conditions and type of applicator; a few of the other sealers operated at 13.56 MHz. The authors found that the electric field near most of the units exceeded the levels permitted in Italian exposure guidelines. However, they noted that the stray fields were essentially confined to the immediate vicinity of the units, so the hands of the operators received the highest exposures, followed by the head and the abdomen.

The authors briefly mentioned that 63 female workers were interviewed for possible health effects; of those, 30 had been exposed, 11 had been partially exposed (those not directly or continuously working at the sealers), and 22 had been unexposed controls. The exposed group reported subjective complaints of eye irritation and upper-limb paresthesia (abnormal sensations such as burning, prickling), with statistically significant incidence relative to the other groups. The laboratory tests given all three groups indicated no compromise of their general health. Clinical examinations of specific organs and systems of the exposed group did not yield evidence that the paresthesias were of neurogenic origin, but "vitreous-body disorganization" in various degrees was observed. The authors cited Desideri et al. (1986) [as in press] for a more detailed description (in Italian) of those health findings.

Kolmodin-Hedman et al. (1988) investigated possible health problems of Swedish workers occupationally exposed to RFR from machines for welding plastics. Selected were workers 30 years old or younger at the start of employment (to include ages of fertility) who were employed for more than 5 years as plastic welders, yielding 51 men and 62 women (113 total). The mean age and employment duration of the women were respectively 39 years and 13 years. The corresponding values for the men were 34 years and 11 years.

As a control group for the women, 23 operators of sewing machines and assembly workers (mean age and employment duration 40 years and 11 years, respectively) were selected on the basis that the repetitive mechanical character of their work was similar to that of the welders. A control group for the men could not be selected because of difficulties in finding matching individuals not occupationally exposed to other potentially harmful agents.

To assess possible effects on fertility outcome, the authors identified 305 currently or previously employed female users of plastic welding machines of all types, and compared their data with the averages of the Swedish birth and malformation registers. No significant differences were found.

The electric and magnetic fields at each plastic welding machine were measured, during normal production, with a Holaday Industries Model HI-3002 calibrated for the frequency range 25-30 MHz. The measurements were made at "standardized" points with respect to the usual posture of the workers during operation: at the right and left hands, abdomen, inguinal region, right and left knees, and right and left feet. During the measurements, the worker was at least 0.5 meter from the probe. The values were used to calculate the mean and the equivalent power densities. The authors noted that the whole-body SAR of each person could not be determined.

No values of power density were presented; instead, tabulated were the numbers of machines (by function) at which the equivalent power density of either the electric field or the magnetic field at any of the standardized points exceeded 250 W/m^2 (the maximum allowable level in the then Swedish exposure standard) or exceeded 100 W/m^2. Of the 113 machines surveyed, 56 (50%) were found to exceed 250 W/m^2 (25 mW/cm^2) and 70 (62%) exceeded 100 W/m^2 (10 mW/cm^2); the highest fields were near the machines used for manufacturing ready-made clothes.

Structured interviews were conducted, including questions on general health, work conditions, previous employment, occurrence of neurasthenic symptoms such as headache and tiredness, incidence of accidental burns, and fertility outcome. All subjects were tested for muscular coordination of the eyes and the smallest distinguishable spacing (in mm) between 2 points touched with a protractor (2-PD test) at the tip of the 2nd finger and on the palm at the base of the 2nd and 5th fingers. On the basis of their reported symptoms, 38 persons were selected for clinical investigation of the neurologic state of their hands and arms and their shoulders and neck, and electroneurography was performed on the persons who reported numbness in the hands. That subgroup was also given eye examinations. In addition, 8 persons from one firm that reported the frequent occurrence of irritative eye symptoms were examined by a ophthalmologist.

From the interviews, the authors derived the information shown in Table 6 (adapted from Table 3 of the paper).

TABLE 6: SMOKING HABITS & GENERAL HEALTH OF PLASTIC WELDERS

[Kolmodin-Hedman et al. (1988)]

Category	% Men Exposed (n=51)	% Women Exposed (n=62)	% Control Women (n=23)
Smokers	29	45	52
Ex-smokers	17	15	4
Non-smokers	53	40	44
Do you feel healthy?	75	76	83
Physiologically hard work	35	36	13
Psychologically stressing work	33	53	26

As seen in Table 6, 83% of the controls reported feeling healthy, but only about 75% of the exposed workers of both genders did so. The percentages of smokers were higher in both the exposed and control women than in the men. About one-third of the exposed women judged their work as physically hard, compared with a quarter of the control women; a third of the exposed men and half of the exposed women found the work psychologically stressing, compared to about a quarter of the control women, with monotony and doing piece-work important factors in such stress.

Not displayed in the table but noted by the authors was that frequent muscular pain was reported by 58% of the exposed women and 62% of the control women, and that about 20% of the exposed group had neurasthenic symptoms compared to 9% in the controls. Tiredness was reported by about 60% of the exposed and control women, but headache was less prevalent in the exposed women: about 42% versus 52% in the controls. However, use of headache pills was higher in the exposed women, but the control women used drugs against hypertension.

Burns were experienced at least once a year by 70% of the women and 60% of the men by accidentally touching metallic objects in the the RF field. Such burns were said to be deep and to require long healing times.

Complaints of eye irritation were most frequent among the tarpaulin welders. The number of machines that exceeded 250 W/m^2, 27 (63%), was highest for that task. However, as noted by the authors, a study of the pyrolysis products of plastic material (mostly PVC) indicated the presence of known eye irritants. Also, only conjunctivitis was found in the subgroup of 8 persons given ophthalmologic examinations.

In the 2-PD tests, 39 exposed persons (17 men and 22 women) had poorer discrimination (larger minimum spacings), compared with only one control woman, a significant difference ($p<0.05$, Mantel-Haenszel chi-square test). The authors also reported a dose-response relationship between numbness and exposure, the latter assessed by both machine type and measured electric field, but no specific data were presented. Of the 38 persons examined by electroneurography, 12 displayed disturbances (slower conductivity velocity

and/or amplitude changes in the spike), of which 7 had signs of carpal tunnel syndrome and 5 of more peripheral disturbance. Of the 23 controls, 5 (22%) experienced numbness.

The findings of this study are difficult to assess because the data presented were insufficient in kind or number to analyze. Specifically, the sizes of the exposed and control populations were small, the intensities and durations of the RFR-exposures could not be characterized adequately, and the influence of other possible (non-RFR) factors could not be distinguished. In addition, the assumption of the authors that the kinds of operations performed by the 23 control women were similar to those of the plastic welders is open to question.

Nilsson et al. (1989) selected 17 radar mechanics and engineers from military technical personnel in western Sweden who probably were exposed to moderate or high levels of RFR, and 12 unexposed or minimally exposed persons as controls. The mean ages of the exposed and control groups were 52 and 51 years, respectively. The subjects were examined by a neurologist without foreknowledge of the exposure histories. Standard psychological tests were done, including verbal, logical, spatial, perception, and memory, to exclude other causes of organic brain dysfunction. Twenty-six of the subjects were interviewed by a psychiatrist for rating of various possible symptoms, also without foreknowledge of the exposure histories.

Twenty-five of the subjects agreed to a lumbar puncture and withdrawal of a sample of cerebrospinal fluid (CSF). Those samples were examined by cytologic analysis and isoelectric focusing before and after absorption chromatography of serum proteins. Samples of CSF from 4 Cynomolgous monkeys were examined for comparison: One monkey had been exposed to pulsed 2.45-GHz RFR at 10 mW/cm² average power density (SAR stated to be 2.6-4.8 W/kg) on 12 consecutive days for 4 hours a day, and another monkey for only 2 hours a day. The third monkey had been exposed similarly to 2.45-GHz CW RFR for 4 hours a day, and the fourth was not exposed to RFR.

All subjects were interviewed by a specialist in occupational medicine, to ascertain their previous working tasks and possible accidental exposure to electromagnetic radiation. Their exposures to various microwave frequencies was estimated, as well as exposures to lower frequencies and to other factors that could have affected their nervous systems, such as electrical accidents and organic solvents.

The authors noted that the most common radar frequency bands used in Sweden are 1.3, 3, and 10 GHz. They also remarked that because the depth of penetration at 10 GHz is only a few millimeters, only frequencies below about 5 GHz were likely to be able to physically cause damage to the central nervous system (CNS). The radar transmitters emitted short-duration pulses (0.1-10 μs) with repetition frequencies of 100-1000 pps, which yielded average powers of a few watts for navigational radar to several kilowatts for air surveillance radar. The RFR levels near some transmitters were measured. The results indicated very low leakage levels. With the magnetron covers removed, however, as is often done by engineers when adjusting the transmitters, the RFR levels from some units exceeded the Swedish threshold limit (1 mW/cm² for any 6 minutes). Also found for some of the older transmitters were remarkably high values of the time derivative of the magnetic flux density, generated by

short-duration, high-current pulses feeding the magnetron. In the one case cited by the authors, the value was 350 T/s, stated to be about a thousand times higher than the levels in front of video display terminals.

There were no significant differences between exposed and control groups in the neurologic examinations. Also, no clinically significant abnormalities were found in the blood tests, and no impairment in psychological performance was observed. Subjective psychiatric symptoms were more common in the exposed than the control group. No individual scores were given, but the means and SDs for the two groups were 7.1 ± 4.7 and 4.9 ± 4.5, respectively, stated to be a nonsignificant difference. On the other hand, objective dementia signs were less prevalent in the exposure group.

The cytologic and chemical analyses of the CSF showed no significant differences between exposed and control groups. Isoelectric focusing of the CSF after absorption chromatography of serum proteins yielded patterns of proteins mainly of CNS origin, in bands related to the isoelectric point (pI) of each protein. Nine of the 13 exposed subjects versus 1 of the 12 controls had an abnormal protein band with pIs in the range 4.4-4.5, a significant difference ($p=0.01$, Fisher's exact test). There were also abnormal proteins at 5 higher pIs, but those differences between groups were nonsignificant.

The CSF of the monkey exposed to the pulsed 2.45-GHz RFR for 4 hours a day also showed a protein band at a pI of 4.5, but only a faint band was seen for the monkey similarly exposed to the CW RFR. The band at 4.5 pI was absent or faint for the unexposed monkey and for the monkey exposed to the pulsed RFR for 2 hours a day. Those results led the authors to surmise that the effects of pulsed RFR are different than those of CW RFR at the same frequency, power density, and duration. However, the authors also remarked that the nature and clinical significance of those protein differences are unclear.

The lack of quantitative information on the emission measurements from the transmitters and of specific data for the exposed and control individuals, as well as other details in this paper (such as details regarding the exposure apparatus and methodology used in the monkey experiments) renders it difficult to lend credence to either the positive or negative findings of this study.

Goldoni (1990) performed hematologic examinations of 14 male radar technicians who worked for 12 hours per day every other day in air traffic control for 7 to 14 years [average 10.14 ± 2.48 years (SD)]. Their ages had a mean of 37.28 (± 7.88) years, and a range of 7 years. They were exposed to pulsed microwaves in the frequency range 1.25-1.35 GHz at intensities from 10 $\mu W/cm^2$ to 20 mW/cm^2 [presumably time-averaged], but generally less than 5 mW/cm^2. Periodically, they entered the near field where the power densities ranged up to 20 mW/cm^2. Those levels were determined with a Raham Model 4A isotropic wideband hazard meter.

Using a Coulter Counter Model S Plus, two counts of the peripheral leukocytes, lymphocytes, erythrocytes, reticulocytes, and thrombocytes were done for each person two years apart. The authors stated that they compared the two sets of counts for the exposed persons with the two-tailed Student's t-test, but did not give the results of that test. Instead, they displayed bar graphs of the thrombocyte and leukocyte counts of each individual, which showed decreases in the two-year interval between the two examinations, and

remarked that by F-ratio, the differences were significant at $p<0.0001$ for the thrombocytes and $p<0.0144$ for the leukocytes. However, they also noted that the initial individual thrombocyte counts and the decreased final values were within normal limits [within the range 100-400 x 10^9 per liter]. Differences in lymphocyte and reticulocyte counts were said to be nonsignificant.

The control group consisted of 10 male electronic technicians who also worked at the airport but far from any microwave sources. Their mean age was 37.6 ± 4.78 years with a range of 14 years. Bar graphs similar to those for the exposed men were not presented for the controls. Instead, the leukocyte and erythrocyte counts for each exposed and control person, from the second examination only, were graphed in increasing order of counts, i.e., the lowest counts for the exposed and control individuals were paired, as were the next lowest counts, and so forth. On this basis, the graphs for both endpoints indicated consistently lower values for the exposed men. However, presenting the data in that manner may be misleading in the absence of a rationale for such pairings. To illustrate this point, although exposed examinee 7 had a lower leukocyte count than control examinee 7, his count was higher than for control examinees 1-4. On the other hand, the authors did state that by F-ratio, the leukocyte and erythrocyte counts of the exposed men were lower than for the controls (respectively $p<0.022$ and $p<0.041$).

The positive and negative findings in this paper are questionable not only for the points noted above, but also for the small numbers of persons examined, the lack of information such as when the two examinations were done relative to the specific exposure periods and durations of the individuals, and why was a two-year interval between the examinations selected.

Hocking et al. (1991) described the management, by Telecom Australia, of potential effects of occupational exposure to RFR on its employees who have implanted medical devices, including orthopedic devices, cardiac pacemakers, and cochlear implants. Of major concern was the amount of local heating of nearby tissues due to enhancement of the external RF fields by such metallic implants. The authors indicated that dental work poses a negligible hazard, because the mouth is an efficient cooling device and teeth are heat-resistant. Possible interference with the operation of some devices by the incident RF fields, such as cardiac pacemakers (from pulse generators) and cochlear implants (by direct RF reception), was also examined.

The basic protocol described includes the following:

(1) Occupational physicians or radiation protection officers and implant recipients are alerted regarding possible adverse interactions.

(2) Details of the implant are obtained, including its configuration, anatomic location, and a radiograph of the device after the operation.

(3) The potential exposure is determined, including frequencies, field strengths, and exposure durations.

(4) The likely heating effect of the RFR-exposure is calculated, with worst-case estimates based on the upper limits of the Australian exposure standard.

(5) The extent of heating is assessed with regard to hazard to adjacent tissues. An upper acceptable limit is 1 °C, but lower limits may be prescribed for devices adjacent to heat-sensitive tissue (such as the atrioventricular node).

(6) Communication of the information to the person and to management in clear understandable terms. Reassessment should be considered for job transfer or introduction of new technology.

Of particular interest is the example, in the appendix to the paper, of a 32-year-old male radio technician who had undergone cardiac surgery, and had 1-mm stainless-steel wire sutures securing his sternum. Those wires formed loops and near-vertical twists about 2 mm in diameter. For RFR-interaction calculations, those structures were regarded as rods and rings. The subject was exposed predominantly to frequencies between 6 and 22 MHz at low levels (≤2 mW/cm²), but could be exposed at the [Australian] 25-mW/cm² allowable limit for up to 8 hours, with provision for a maximum short-term (6-minute) exposure of up to 100 mW/cm². He may be required also to work at frequencies above 30 MHz, for which the limit is 1 mW/cm² for up to 8 hours, with short-term limit of 5 mW/cm².

Two methods were described in detail for assessing the RFR-interactions with the implant. The electric-field enhancement factors of the structures were determined, the incident electric fields on the implant from exposure of the person at the maximum allowable RFR limits were calculated, and both were used to calculate the *in-situ* electric fields that could cause tissue heating. Based on heat-transfer calculations, the rises in tissue temperature at the RFR frequencies of interest were tabulated for the indicated exposure limits. The largest temperature rise shown was 2.4 °C, in the frequency range 1.65-3.0 GHz, for which the short-term exposure limit is 5 mW/cm². The next highest rise was 1.3 °C at 80 MHz (whole-body resonance), for which the short-term exposure limit is also 5 mW/cm². The other temperature rises shown were all well below 1 °C. The advice given to the subject and to the management was to permit work at exposure levels up to the occupational limits for frequencies below 30 MHz, but that no work was permitted at the maximum short-term limits in the range 50-150 MHz and in the gigahertz range.

Isa and Noor (1991) described three cases of occupational exposure to RFR who were treated in a Malaysian outpatient clinic. The first patient had maintained 1-kW TV transmitters while they were off during 2-hour sessions in the transmitter room for 11 years; during the 12th year, however, another transmitter was on while he was doing such maintenance. The other two cases had worked as aerial riggers, installing and maintaining antennas on 400-foot towers for about 10 years with the transmitters off, but did the same work during the 11th year with the transmitters on.

The three patients displayed symptoms of neck strain accompanied by throbbing headache, irritability, appetite loss, fatigue, memory difficulties, and numbness in the extremities. All three patients also exhibited *alopecia areata* (a patchy loss of hair) at specific areas of the head. Blood and other laboratory tests on the three patients yielded results within normal ranges, but scalp biopsies confirmed *alopecia areata*. Steroid injections into the bald areas produced complete hair regrowth. The authors indicated that the subjective symptoms above were reversible. In the absence of data on the RFR

levels in the transmitter rooms in which the first patient worked, it is difficult to ascribe any credence to the authors' opinion about a link between the occurrence of *alopecia areata* and chronic exposure to RFR. Regarding the two aerial riggers, it is conceivable that the RFR levels were within the range that can cause deleterious thermal effects (whole-body SARs well above 4 W/kg), a point noted by Jauchem (1993).

Papandreou et al. (1992) discussed the case of an army officer suffering from *mediastinal fibrosis* (the presence of a dense fibrous mass between the lungs), which produced a significant occlusion of the left pulmonary artery, with poor perfusion of the left lung. The authors suggested that the illness may have been associated with his exposure to RFR while serving at a Greek radar base for 18 years, where he had frequently entered (unauthorized) the antenna main beam of an "improved high-powered illuminator radar" at distances where the power densities exceeded 1 mW/cm^2, the maximum permissible exposure level. The frequencies or other characteristics of the illuminator radar were not described. The patient was a smoker ("24 pack years"), and previously had been cured of double vision. Without other information on his lifestyle and the fact that this is the only such case in medical records, it seems unlikely that the patient's illness was due to RFR-exposure, a conclusion also reached by Jauchem (1993) and Hocking and Joyner (1993). Hocking and Joyner (1993) also noted that such radars usually operate at about 6 GHz, a frequency that does not penetrate very far into wet human tissues, and that the power density at the affected region of the body would only be a few nanowatts per cm^2.

2.2.1 SUMMARY ON RFR AND GENERAL HEALTH

The findings of the various studies on whether exposure of the general population or occupationally to RFR affected their health are summarized briefly in Table 7 (A, B, C, D, E, and F).

Authors	Effects Sought or Examined	Exposure Modality	Effects Reported	Notes & Comments
Pazderová (1971)	Clinically significant differences between exposed and control groups of both genders in Czechoslovakia.	Occupational exposure to TV transmitters that emitted 48.5-230 MHz RFR at up to 9.2 V/m (0.022 mW/cm^2).	Neurotic complaints were less frequent in the exposed than the control group. The only significant difference was a higher mean plasma protein level in the exposed group.	Medical histories of subjects were recorded and each was given a complete medical examination, including blood tests and eye, neurologic and psychiatric examinations.
Pazderová et al. (1974)	Mostly changes in the levels of blood-plasma proteins, such as those reported by Pazderová (1971).	Exposure to RFR from transmitters emitting 60-300 MHz at 0.5-9 V/m, 3-30 MHz at 66 V/m, and 640-1500 kHz at 55 V/m.	All mean and individual blood-protein levels and their fractions were within normal physiologic limits, but there were significant frequency-band-dependent differences in mean values for the exposed and control groups. However, the changes differed from those of the previous study, e.g., no elevation of gamma-globulin was seen.	Separate groups were exposed to the three frequency bands, designated as TV, SW, and MW, with a control group for each. The differences in findings of the two studies vitiate the validity of either study.
Klimkova-Deutschova (1974)	Computer analysis of 119 health parameters in Czechoslovak" workers.	Occupational exposure of metal and plastic welders, steel temperers, TV and radio technicians, and others to RFR and various other agents.	Various effects were reported, including EEG disorders and biochemical changes, described as nonthermal RFR effects, but the author indicated that most of the subjects suffered less serious injury than some groups that used noxious chemicals.	The RFR levels and exposure durations for most groups were not given. The author noted when the differences among groups for specific endpoints were significant, but did not give any data or statistical treatment. Little credence is given to the findings.
Kalyada et al. (1974)	Clinical changes due to exposure from RFR generators in the USSR.	Occupational exposure to RFR in the range 40-200 MHz at not stated nonthermal levels or durations.	No organic lesions were found, but functional changes in the central nervous system were reported, principally as "vegetative dysfunction accompanied by neurasthenic symptoms".	The findings were presented in narrative form, with no data given. Changes in a few endpoints relative to controls were shown as bar graphs, but no statistical treatment was given. Findings questionable.
Sadčikova (1974)	Clinical changes in health status of two groups of USSR workers.	RFR-exposure from tuning, testing, and regulating microwave emitters, one group at levels up to a few mW/cm^2 and another up to a few hundredths of a mW/cm^2, at unstated frequencies.	The results were shown in bar-graph form with error bars for percentage changes in 5 neurologic, 6 autonomic-vascular, and 5 cardiac symptoms. The changes in the higher-RFR group were larger than for the control group for all symptoms except arterial hypertension. Similar results were found for the lower-RFR group relative to controls, but for 11 of the 16 symptoms, the differences were larger for the lower-RFR than the higher-RFR group. Lens opacities in both groups did not exceed control values.	The mixed findings, notably the larger differences for the lower-RFR group, render doubtful that RFR was the causative agent. The author described the "asthenic syndrome" and "microwave sickness," neither of which is found in Western RFR-bioeffects studies.

TABLE 7A: RFR AND GENERAL HEALTH

Authors	Effects Sought or Examined	Exposure Modality	Effects Reported	Notes & Comments
Siekierzynski (1974)	Health status and work fitness of two groups pulsed-radar workers in Poland.	Group I at average power densities that exceeded 0.2 mW/cm², and Group II at 0.2 mW/cm² or less, both at unspecified radar frequencies. Highest level for Group I was 6 mW/cm² for short times (Siekierzynski et al., 1974a).	The subjects were given slit-lamp eye examinations and neurologic checkups plus psychological tests and EEGs. Other details were described in Czerski et al. (1974a), and Siekierzynski et al. (1974a, 1974b). The data and their statistical treatment were presented in a set of tables. No significant effects of the RFR were found regarding the health status of either group.	An unexposed comparison group for Group I was difficult to obtain, so Group II served as the controls, an expedient that weakens the validity of the negative finding.
Robinette and Silverman (1977)	RFR-related higher mortality.	Occupational exposure to RFR of personnel who served in the U.S. Navy during the Korean war (levels and durations not estimated).	No significant differences were found between the high-exposure and low-exposure groups in deaths from all causes. The death rates from trauma were significantly higher in the high-exposure group, but were not RFR-related.	The high-exposure group was picked by occupational titles Electronics Technician, Fire Control Technician, Aircraft Electronics Technician. The titles of the low-exposure group were Radioman, Radarman, Aircraft Electrician's Mate.
Silverman (1979) [Review paper]	See Robinette and Silverman (1977).	See Robinette and Silverman (1977). Some in the high-exposure group were exposed at levels exceeding 10 mW/cm² at some times on some ships, but those in the low-exposure group were exposed at well below 1 mW/cm².	There were no significant RFR-related differences between the high-exposure and low-exposure groups in long-term-mortality or hospitalization patterns. No morbidity data were presented in Robinette and Silverman (1977) or in this review paper.	Other Naval personnel were added to those included in Robinette and Silverman (1977).
Robinette et al. (1980)	Same as Robinette and Silverman (1977). In addition, the numbers of admissions to Naval hospitals in various periods and admission rates for both groups were compared by ICD* diagnoses.	See Robinette and Silverman (1977).	Only 2 of the 18 comparisons between the high-exposure and low-exposure groups were significant: The low-exposure group had higher admission rates for mental disease, and for accidents, poisonings, and violence. The admission rates did not differ between groups for any disease class.	ICD = International Classification of Disease. The use of occupational titles is open to question, but the large numbers of persons and the estimated exposure levels lend considerable weight to the negative findings.
Forman et al. (1982)	Health effects of an accidental exposure of two military men to high-level RFR, one for 80 seconds and the other for 75 seconds.	Operation of X-band CW radar tracking system; probable electric field strength about 580 V/m; 90 mW/cm² free-space equivalent.	Hypertension was diagnosed in both men, but no secondary cause was found. No lenticular opacities were evident. Neurologic results were normal, and various psychological tests showed no evidence of organicity. The overall diagnosis for both men was acute post-traumatic stress disorder.	Each man exhibited various postexposure physiological and psychological symptoms, and were given extensive medical, ophthalmologic, endocrine, and psychiatric examinations.

TABLE 7B: RFR AND GENERAL HEALTH (CONTINUED)

Authors	Effects Sought or Examined	Exposure Modality	Effects Reported	Notes & Comments
Djordjević et al. (1979)	Effects on 322 radar workers in Yugoslavia of occupational exposure to pulsed microwaves for 5-10 years. The controls were 220 persons matched in age, and in working, social, and living conditions.	Frequencies or other characteristics were not given, but power-density measurements indicated that the workers generally were exposed to less than 5 mW/cm².	The numbers and percentages of exposed and control subjects diagnosed for various ailments were tabulated. Most prevalent was "Neurocirculatory Asthenia," in 49 (15.2%) of the exposed subjects and 29 (13.2%) of the control subjects; the difference was said to be nonsignificant. The differences between groups for the other ailments were also nonsignificant. The authors concluded that prolonged occupational exposure to microwaves did not affect the health status of the radar workers.	Clinical examinations included detailed internal, neurologic, ophthalmologic, otologic, hematologic, and biochemical investigations. Although health status was not affected by RFR-exposure, the lack of statistical treatment of the data diminishes the credibility of that finding. "Neurocirculatory Asthenia" is a disorder not recognized in Western medicine.
Djordjević et al. (1983)	A 15-year clinical study for the years 1970, 1975, and 1980 of 500 occupationally RFR-exposed workers; 350 controls were used for comparison.	Unstated frequencies in the centimeter-wave band, for about 2 hours daily at levels usually less than 5 mW/cm².	"Neurovegetative Dystonia" was the most prevalent diagnosis, seen in 17% of the exposed group versus 20% in the control group for 1970; in 12% versus 8.8% for 1975; and in 15% versus 10% for 1980. The authors noted that the differences for each year were not significant, but gave no statistical treatment.	Unclear is whether some or all of the data from Djordjevich et al. (1979) were included. The comment above about the lack of statistical treatment applies here as well. "Neurovegetative Dystonia" is also not recognized in Western medicine.
Lilienfeld et al. (1978)	Health effects of RFR-irradiation of the US Embassy in Moscow on the personnel assigned there and their dependents.	Details are given in Pollack (1979) and in NTIA (1981). Signals were in the range 0.5 to 10 GHz. Highest level was 24 μW/cm² for a 2-hour period.	Medical records of (US) Moscow employees and their dependents were compared with those of employees and dependents in the embassies and consulates in various Eastern European cities during the same period. No discernible differences were seen between Moscow and control groups in total mortality or mortality from specific causes, or in mortality between groups of dependent children or adults.	The authors recognized the limitations of this study due to their inability to acquire full sets of medical records, death certificates, and health questionnaire returns, and to the imprecision in classifying the probable extent of RFR-exposure of each employee.
Hamburger et al. (1983)	Health effects on male physical therapists from use of various diathermy modalities on patients, based on therapist responses to a questionnaire.	Surveys by Ruggera (1980) of diathermy units yielded mean equivalent power densities for 2.45-GHz units well below 1 mW/cm². For 27-MHz units, the magnetic-component levels were 1-2.5 mW/cm² and the electric-component levels were 1.2-4.1 mW/cm².	The modalities were: "microwave (M), shortwave (S), infrared (I), ultrasound (U)". Subgroups were formed for each modality and combined modalities, but some small-size groups were merged. No significant differences were found for the U or I subgroups, but the all-four-modalities (IMSU) subgroup showed significantly higher rates for heart disease than for the other subgroups. A similar finding was reported in the new subgroups formed: "microwave, shortwave, joint microwave/shortwave exposure".	The small numbers in various subgroups and their merging into larger groups, the absence of supporting results in animal experiments, and the use of self-reported responses to a questionnaire raise strong doubts regarding the validity of the heart-disease finding.

TABLE 7C: RFR AND GENERAL HEALTH (CONTINUED)

Authors	Effects Sought or Examined	Exposure Modality	Effects Reported	Notes & Comments
Burr and Hoiberg (1988)	Hospitalization rates for Naval pilots of "electronically modified aircraft" (test group) versus the rates for pilots of other types of aircraft (controls).	Test group presumed exposed to higher ionizing-radiation levels (at higher altitudes) and higher nonionizing-radiation levels (from onboard antennas & electronic equipments) than control group.	The controls in age group 21-26 years had a significantly higher mortality rate for aviation-related injuries, and higher hospitalization rates for accidents, poisonings, and violence than the test group. The controls in age group 27-32 years had a significantly higher hospitalization rate for mental disorders than the test group. However, neither group had any hospitalizations related to presumed ionizing-radiation or nonionizing-radiation exposure.	Although the results for both ionizing and nonionizing radiation were negative, the validity of the findings could be questioned because neither the exposure levels nor the exposure durations were measured or estimated.
Kolmodin-Hedman et al. (1988)	Health problems from occupational exposure of men & women to RFR from plastic welding machines of various types in Sweden. The findings were based on interviews regarding general health and history, and on tests of eye coordination and neurologic state.	Electric and magnetic fields in the range 25-30 MHz were probed at each welding machine. No numerical values were given, but the numbers of machines for which either the electric field or the magnetic field exceeded the then Swedish exposure standard were shown.	Operators of sewing machines comprised the control group for female welders; an adequate control group for male welders could not be found. The fertility outcome of the female welders did not differ significantly from the averages of Swedish birth and malformation registers. About 83% of the control women reported being healthy, compared with about 75% of the welders of both genders.	Assessment of the results of this this study is difficult because the data presented were insufficient in kind or number to analyze.
Nilsson et al. (1989)	RFR effects in radar mechanics & engineers, based on neurologic tests including assays of cerebrospinal fluid (CSF); psychological and psychiatric tests.	Pulsed 1.3-, 3-, and 10-GHz RFR at a few watts average power from navigational radars, and several kilowatts from air-surveillance radars. CSF assays also done on 2 monkeys exposed at 10 mW/cm^2 (SAR 2.6-4.8 W/kg) to 2.45-GHz pulsed RFR, 1 monkey to CW RFR, and on 1 unexposed monkey.	No significant differences were seen between the exposed and control groups of humans in the neurologic and psychological tests or in the CSF assays. However, the monkey CSF assays showed some differences between CW and pulsed exposure.	Measurements made near some transmitters showed very low RFR leakage levels, but with the magnetron covers removed, some of the levels exceeded Swedish exposure guidelines. Little credence can be given to either the positive or negative findings of this study because of the paucity of details on both the human and animal aspects.

TABLE 7D: RFR AND GENERAL HEALTH (CONTINUED)

Authors	Effects Sought or Examined	Exposure Modality	Effects Reported	Notes & Comments
Goldoni (1990)	Hematologic effects in 14 radar technicians (male) in air traffic control. The controls consisted of 10 male electronic technicians who worked at the airport but far from any microwave sources.	Pulsed 1.25-1.35 GHz RFR for 7-14 years at power densities of 10 $\mu W/cm^2$ to 20 mW/cm^2, generally but less than 5 mW/cm^2. They periodically entered the near field where the levels ranged up to 20 mW/cm^2.	Two counts were done of the peripheral leukocytes, lymphocytes, erythrocytes, reticulocytes, and thrombocytes for each person two years apart. Bar graphs of thrombocyte and leukocyte counts of the exposed men indicated decreases in the 2-year interval between the two tests, results stated to be significant, but similar graphs were not shown for the controls. In addition, the lower final values were within normal limits. No significant differences in lymphocyte and reticulocyte counts were reported.	Both the positive and negative findings are open to question, mostly because of the small numbers of persons examined.
Hocking et al. (1991)	The authors described the Telecom-Australia basic protocol on occupational exposure to RFR for employees who have medical implants such as orthopedic devices, cardiac pacemakers, and cochlear implants.	An example was given of a radio technician who had had cardiac surgery, and had 1-mm stainless-steel wire sutures securing his sternum. He was exposed to low levels (≤ 2 mW/cm^2) of 6-22 MHz RFR, but could be exposed for up to 8 hours at 25-mW/cm^2 or for 6 minutes at up to 100 mW/cm^2 [the allowable Australian limits]. He may also have to work at above 30 MHz, but within the limits for those frequencies.	The electric-field enhancement factors of the structures were determined, the incident fields on the implant from exposure of the person at the Australian RFR limits were calculated, and both were used to calculate the *in-situ* fields that could cause tissue heating. From heat-transfer calculations, the tissue-temperature rises at the RFR frequencies of interest were tabulated for the indicated exposure limits. The largest temperature rise tabulated was 2.4 °C, in the frequency range 1.65-3.0 GHz, for which the short-term (6-minute) exposure limit is 5 mW/cm^2. The next highest rise was 1.3 °C at 80 MHz (near whole-body resonance), for which the short-term exposure limit is also 5 mW/cm^2. The other temperature rises were all well below 1 °C.	The advice given the subject and management was to permit work at exposure levels up to the occupational limits for frequencies below 30 MHz, but not to permit the subject to work at the maximum short-term limits in the range 50-150 MHz or in the gigahertz range.

TABLE 7E: RFR AND GENERAL HEALTH (CONTINUED)

Authors	Effects Sought or Examined	Exposure Modality	Effects Reported	Notes & Comments
Isa and Noor (1991)	Discussion of three cases of occupational exposure to RFR treated in a Malaysian outpatient clinic.	The first case had maintained 1-kW TV transmitters during 2-hour sessions in the transmitter room for 11 years, with the transmitter off; during the 12th year, another transmitter was on while he was doing maintenance. The other two cases worked as aerial riggers, installing and maintaining antennas on 400-foot towers for about 10 years with the transmitters off, but did the work during the 11th year with the transmitters on.	The three patients displayed symptoms of neck strain accompanied by throbbing headache, irritability, appetite loss, fatigue, memory difficulties, and numbness of extremities. In addition, all three exhibited *alopecia areata* (a patchy loss of hair) at specific areas of the head. Blood and other laboratory tests on the three patients yielded results within normal ranges, but scalp biopsies confirmed *alopecia areata*. Steroid injections into the bald areas produced complete hair regrowth. The authors noted that the subjective symptoms above were reversible.	In the absence of data on the RFR levels in the transmitter rooms in which the first case worked, it is difficult to ascribe any credence to the authors' opinion about a link between *alopecia areata* and chronic exposure to RFR. Regarding the two aerial riggers, it is conceivable that the RFR levels were within the range that can cause deleterious thermal effects (whole-body SARs well above 4 W/kg), a point noted by Jauchem (1993).
Papandreou et al. (1992)	The case of an army officer with a severe illness suggested to be associated with his exposure to RFR while serving at a Greek radar base for 18 years.	Frequent unauthorized RFR-exposure in the antenna main beam of an "improved high-powered illuminator radar" at levels exceeding 1 mW/cm². The frequencies or other characteristics of the radar were not described.	The presence of a dense fibrous mass between the lungs *(mediastinal fibrosis)* that caused a significant occlusion of the left pulmonary artery, with poor perfusion of the left lung.	The patient was a smoker ("24 pack years"), and previously had been cured of double vision. Without other data on the patient's lifestyle and the fact that this is the only such case in medical records, it seems unlikely that the patient's illness was due to RFR-exposure, a conclusion also reached by Jauchem (1993) and Hocking and Joyner (1993). The latter authors suggested that such radars operate at about 6 GHz, a frequency that does not penetrate very far into wet human tissues, and that the power density at the affected region would only be a few nanowatts per cm².

TABLE 7F: RFR AND GENERAL HEALTH (CONCLUDED)

2.2.2 CONCLUSION

Deleterious effects from occupational RFR-exposure have been reported in some of the Eastern European studies, such as by Klimkova-Deutschova (1974), Kalyada et al. (1974), and Sadčikova (1974), but not in other studies, such as by Pazderová (1971), Pazderová et al. (1974), or Siekierzynski (1974). By contrast, the results of Burr and Hoiberg (1988) for Naval pilots, Lilienfeld et al. (1978) on Moscow-embassy personnel, and by Robinette and Silverman (1977), Robinette et al. (1980), and Silverman (1979) on Navy veterans were negative. The clinical studies by Djordjević et al. (1979, 1983) and Nilsson et al. (1989) of radar workers, and by Kolmodin-Hedman et al. (1988) on men and women occupationally exposed to RFR from plastic-welding machines also reported negative findings, but their results were difficult to assess because the data were inadequate for analysis or lacked statistical treatment.

Goldoni (1990) found decreases in peripheral thrombocyte and leukocyte counts in air-traffic-control radar technicians and no differences in their lymphocyte or reticulocyte counts, but both the positive and negative findings were questionable because of inadequate treatment of the data. Hamburger et al. (1983) observed a higher heart-disease rate in the "microwave/shortwave" subgroup of male physical therapists but the small numbers in the initial treatment-modality subgroups required merging them into larger but fewer subgroups, a questionable procedure.

Taken collectively, the findings of the various epidemiologic studies do not indicate that chronic RFR-exposure at levels within the ANSI/IEEE (1992) guidelines for uncontrolled conditions would be hazardous to human health. Of interest in this context is the description, by Hocking et al. (1991), of the Telecom-Australia basic protocol for occupational exposure of employees who have medical implants.

Isa and Noor (1991) suggested that *alopecia areata* (patchy loss of head hair) exhibited by one transmitter technician and two aerial riggers of tower antennas could have been due to RFR-exposure. Also, Papandreou et al. (1992) described the case of a Greek army officer suffering from *mediastinal fibrosis* (the presence of a dense fibrous mass between the lungs), causing significant occlusion of the left pulmonary artery and poor perfusion of the left lung. That patient frequently had been exposed to power densities exceeding 1 mW/cm^2 in the main beam of an "improved high-powered illuminator radar" of otherwise unstated characteristics. However, Hocking and Joyner (1993) suggested that typical radars of that kind operate at about 6 GHz, a frequency at which the penetration depth in human tissues is minuscule. Thus, little if any credence can be given to the findings of either study.

2.3 RFR AND CONGENITAL ANOMALIES

Two studies were done that sought a possible relationship between the occurrence of Down's syndrome ("mongolism") and presumed exposure of the fathers to RFR from radars during military service. In the first study, Sigler et al. (1965) examined the data, derived from Baltimore hospital records and interviews with parents, on 216 Caucasian children with Down's syndrome. The case children were matched with 216 control children for hospital of birth (or birth at home), sex, and birthdate (within 6 months), and nearly all were matched for maternal age (within 1 year) at time of birth. Parents were also matched for birthplace, residence, and hospital treatment.

The exposure histories of the mothers were categorized as: diagnostic radiation excluding fluoroscopy, fluoroscopic examinations, radiation for therapy, and occupational contact. One statistically significant finding was that the percentage of case mothers that had received fluoroscopy before the birth of the case child was significantly higher than for the control mothers. The percentage of case mothers who had received at least one therapeutic radiation exposure (mostly for skin ailments) and the percentage of case mothers who had worked in a professional or technical capacity in medical fields were also significantly higher than for the control mothers.

The difference in the percentages of case and control fathers that had served in the military was nonsignificant, but a higher percentage of case fathers reported close association with radars as technicians or operators than the control fathers. The authors thus ascribed the higher incidence of Down's syndrome primarily to greater exposure of the case mothers to ionizing radiation, but concluded: "The only truly puzzling association is the suggested relationship between Mongolism and paternal radar exposure."

In the second study, Cohen et al. (1977) reexamined the data in the first study, denoted as the "Original Series," together with the data on 128 additional matched pairs denoted as the "Current Series". They concluded that the findings for the Current Series did not confirm the suggestions that the fathers of the children with Down's syndrome previously did have excess radar exposure or a larger proportion of military experience.

Peacock et al. (1971) endeavored to assess whether the incidence of birth defects in Alabama could be associated with proximity of military bases. They examined a state-wide file of birth certificates by counties and found an overall rate of 10.3 newborns with anomalies per thousand births, a rate that was comparable to those in other registries. However, a more detailed study of the data showed that there were 17 anomalies per thousand births for the military personnel in the six-county area surrounding Fort Rucker, whereas the anomaly rate for civilian births was only 6.8 per thousand.

Subsequently, Peacock et al. (1973) reassessed the premise, but with data spanning four years rather than the 17 months examined previously. Also, the data were corrected and rendered more accurate than previously, and a more precise test of the reliability of inferences was performed that did not rely on the questionable use of a normal approximation. After accounting for "non-radar" factors, the authors repeated the analyses for the Fort Rucker area and specifically for Lyster Hospital (within Fort Rucker). In addition, as a "control" test, they compared the fetal death anomaly rates in the military hospitals at Fort Rucker and Eglin Air Force Base (which they designated as "radar bases") with those of three military hospitals in bases with minimal radar networks.

The results of the retests confirmed that the total anomaly rate and the rates for several specific anomalies were abnormally high at Lyster Hospital. Also, the numbers of fetal deaths for Lyster hospital and the hospital at Eglin Air Force Base were comparable and "constitute evidence that the problem may be associated with radar".

Burdeshaw and Schaffer (1977) reexamined the original Alabama birth records, but compared the data for Coffee and Dale Counties (within which Fort Rucker is located) with the data from each of the other 65 counties in Alabama

on a score and rank basis instead of the statewide averages. They found little evidence that the incidence of congenital anomalies in the Fort Rucker area was unusually high. The overall rate at Lyster Hospital was well within the expectations for hospitals having characteristics similar to those of Lyster. When the addresses of mothers of anomalous infants were plotted on county road maps, no significant clustering was found, notably in the vicinity of presumed radar sites. The increased incidence of congenital anomalies at Lyster Hospital was found to be attributable to a higher than normal reporting rate of one physician who apparently included "birth defects" not considered such by other physicians.

Thus, these negative findings superseded those of the two studies by Peacock et al. (1971, 1973).

Källén et al. (1982) hypothesized that physiotherapists (in Sweden) were likely to have been exposed occupationally more than the general population to various agents (chemicals, drugs, X-rays, RFR). To test this surmise, they did a cohort study on 2,043 infants born during years 1973 to 1978 to 2,018 women who were registered as physiotherapists during their pregnancies. By crosslinking files in two major computer-based registers, the authors were able to identify infants of mothers registered as physiotherapists at delivery time. They then analyzed this cohort for perinatal mortality and the presence of malformations by comparing the data with information on all deliveries in the Swedish Medical Birth Register.

The results showed that for all endpoints, the expectation values for the total cohort were statistically better than, or comparable to, those for the general population. The authors noted that this excellent outcome could have been the result of a "healthy worker" effect, so they hypothesized that if hazardous exposure had occurred, it should be more common among the few females who had dead or malformed infants than among those who had normal babies. Accordingly, they did a case-control study within the cohort, in which they selected 37 infants who had major malformations or those that did not but had died perinatally. Each malformed or dead infant was compared with two normal infants matched for maternal age, parity, and season of delivery (to compensate for work seasonality). Exposures for case and control mothers were estimated from the answers to a questionnaire that asked (in part):

"Did you, during the pregnancy, work with or in close proximity to the following:

Shortwave equipment: daily/often/seldom/never
Microwave equipment: daily/often/seldom/never
Ultrasonic equipment: daily/often/seldom/never
X-Ray equipment: daily/often/seldom/never
Electrostimulator: daily/often/seldom/never

"Did you use hexachlorophene-containing soap (e.g., Phisohex): daily/often/seldom/never"

On careful review and interpretation of the results, the authors concluded that the physiotherapists as a group had a slightly better-than-expected outcome for perinatal deaths and major malformations than did the general Swedish population for the same period. They did report that the use

of shortwave equipment was higher among those who gave birth to a malformed or perinatally dead infant. However, it is noteworthy that those results would change from borderline significance to nonsignificance if one or two answers to the questionnaire were based on faulty recall.

Thus, the Källén et al. (1982) study actually yielded fewer dead or malformed infants of physiotherapists presumed to have been occupationally exposed to various agents than in the general population. The data base for the cohort part of the study was large, yielding statistically credible negative findings. However, the use of a questionnaire in the case-control part renders questionable the finding of a possible weak association of malformed or perinatally dead infants with the use of shortwave equipment.

Taskinen et al. (1990) did a study of all registered physiotherapists in Finland who had become pregnant during the study period, to determine whether their occupational exposure to various patient-treatment modalities, including RFR, is associated with spontaneous abortion or congenital malformations in their offspring. The subjects were those who had been treated for spontaneous abortion during 1973-1983 or had a malformed child during 1973-1982.

Data were obtained on ultrasound exposure, exposure to shortwaves, and physical exertion from the responses to questionnaires mailed to 1329 female physiotherapists. Selected initially were three age-matched controls (± 18 months) for each abortion case and five controls for each malformation case. One pregnancy per woman was randomly chosen for study. Traced were 1020 of 1047 women (275 cases and 745 controls) for the spontaneous-abortion aspect, and responses were obtained from 247 cases and 693 controls. After removal of unrecorded pregnancies, the final spontaneous-abortion populations were 204 cases and 483 controls. Similarly traced were 309 of 314 physiotherapists for the congenital-malformation aspect (51 cases and 258 controls), of whom 47 and 227 responded. The final congenital-malformation populations were 46 cases and 187 controls.

For assessing exposures of the therapists, the authors classified the equipment used in treating patients by mode of action: They characterized the intermittent or continuous use of electromagnetic shortwave equipment, usually at 27.12 MHz, as "deep heat therapy" because of the deep penetration of such waves into tissues. [Note: the wavelength equivalent of 27.12 MHz is 1106.19 cm, not 12.2 cm mentioned by the authors.] Ultrasound exposure at frequencies in the range 0.5-3 MHz was analyzed separately because the therapist usually holds the ultrasound applicator in her hand throughout the treatment session. Various electric-current treatments for pain (listed as transcutaneous nerve stimulation, diadynamic currents, electrogalvanic stimulation, interference current, laser?) and for activation of muscles were grouped together, as were the various types of equipment that produce superficial heat ("hydrocollator" packages, infrared, ultraviolet). Exposure duration was defined as the amount of time the therapist handled the operating equipment while standing close to it (at distances of 1 meter or closer).

The authors used linear logistic regression for individually matched data, and evaluated significance in terms of odds ratios (ORs) relative to estimates based on a normal distribution. The 95% confidence intervals (CIs) were calculated from the standard errors of the estimates. Significance for homogeneity of the ORs relative to pregnancy duration was determined by using

a dummy variable to separate the cases with gestation times of 10 weeks or shorter from those with gestation times exceeding 10 weeks, and including the interaction of that variable with the exposure variable in the logistic model.

From the data gathered, ultrasound exposure was most often reported (115 cases and 256 controls). Analysis showed that handling ultrasound equipment for at least 20 hours per week increased the risk of spontaneous abortion significantly ($p<0.05$): OR = 3.4; CI = 1.2-9.0, but those subpopulations were small (9 cases and 8 controls). Also, exposures for less than 20 hours a week (106 cases and 248 controls) yielded ORs slightly exceeding 1.0 but with CIs that spanned 1.0. Administering electric therapies for at least 5 hours per week also showed a significant increase of spontaneous-abortion risk: OR = 2.0; CI = 1.0-3.9. Physical exertion by the therapists was the only other factor that showed a significant increase ($p<0.05$) of spontaneous-abortion risk. Specifically, heavy lifting (weights exceeding 10 kg) and/or transfer of patients 50 or more times a week yielded an OR of 3.5 and CI of 1.1-9.0. The extent of massage or mobilization therapy given by therapists had no influence on spontaneous-abortion risk.

For deep-heat therapy overall and spontaneous abortion, the OR for 1-4 hours a week was 1.2 with a CI of 0.8-1.9, but was 1.6 with a CI of 1.0-2.7 for 5 or more hours a week (not labeled significant by the authors). As shown, this treatment class consisted of shortwaves and microwaves, but the authors did not provide any information about the microwave frequencies or any other details regarding such exposures. The ORs for each modality exceeded 1.0, but the CIs spanned 1.0 for both 1-4 hours per week and 5 or more hours per week of usage.

From the analysis by pregnancy duration, heavy lifting during pregnancy durations of 10 weeks or shorter was the only factor that contributed to a significant risk for spontaneous abortion: OR = 3.8 ($p<0.05$, no CI shown). On the other hand, for pregnancy durations exceeding 10 weeks, significant risks were indicated for using deep-heat-therapy equipment (including those emitting shortwaves) for 5 or more hours a week (OR = 2.6, $p<0.01$), and specifically for shortwaves (OR = 2.5, $p<0.01$). Similarly, the results for ultrasound and for infrared heating for 10 or more hours a week were respectively: OR = 3.4, $p<0.01$ and OR = 1.7, $p<0.05$. As discussed below, the authors regarded these results and the absence of significant risk increases for pregnancy durations 10 weeks or shorter as indicative of a dose-response relationship. Heavy lifting was a significant factor again, but for both ranges of pregnancy duration ($p<0.05$).

The homogeneity analysis of the ORs with respect to the two pregnancy-duration ranges yielded $p<0.05$ for the deep-heat therapies as a class, $p<0.05$ specifically for shortwaves, and $p<0.01$ for the ultrasound therapy. However, a univariate analysis of possible confounding factors showed that spontaneous abortion was significantly associated with failures of the contraceptive devices used by the women (OR = 2.0, CI = 1.0-3.7; $p<0.05$), as were previous spontaneous or induced abortions (OR = 1.8, CI = 1.0-3.1; $p<0.05$).

The results for congenital malformations (46 cases and 187 age-matched controls) showed a significant increase in risk for administering deep-heat therapy: OR = 2.4, CI =1.0-5.3; $p<0.05$ for 1-4 hours per week but not for 5 or more hours a week: OR = 0.9, CI =0.3-2.7. Specifically for shortwaves, the

results for 1-4 hours per week were significant (OR = 2.7, CI =1.2-6.1; $p<0.05$), but were nonsignificant for 5 or more hours a week (OR = 1.0, CI = 0.3-3.1). The authors suggested that bias due to selective recall cannot be excluded in this part of the study but they discounted such bias in the spontaneous-abortion part.

The only other modality that indicated a significant risk increase of congenital malformations was for transcutaneous nerve stimulation for more than 5 hours a week (OR = 4.7, CI = 1.2-18.7, $p<0.05$). No significant risk increase was seen for congenital malformations from the use of microwaves (OR = 0.5, CI = 0.1-3.9).

The authors concluded: "The results of this study suggest that heavy physical exertion is a risk factor for spontaneous abortion. The effect of shortwaves and ultrasound on the 'late' spontaneous abortions was significant and increased in a dose related manner. On the other hand, in the multivariate analyses neither the effects of ultrasound nor shortwaves reached statistical significance. Therefore, the finding has to be interpreted cautiously. The finding of an association between the exposure to shortwaves and congenital malformations does not justify conclusions of a causal relationship."

The authors are rightly cautious in interpreting their findings; as in other studies, responses to questionnaires are often unreliable. Based on the high and similar response rates for the cases and controls in the spontaneous-abortion part of the study, the authors remarked that selective participation was not likely. However, they suggested that selective reporting or recall bias could be excluded as well in that part of the study because of "dose-response relationships, effects of gestational length, differences in results between spontaneous abortions and malformations (because bias should affect them in the same way), and uniformity of effects between the two periods analyzed". In the absence of any data on exposure levels and their variations with time and patient-treatment site, the authors' use of the term "dose" as in "dose-response relationships" is meaningless quantitatively, and their remarks about the other points in the quotation above are obscure at best. Thus, at least with regard to RFR, little if any credence can be given to either the positive or negative findings of this study.

Larsen et al. (1991), noting a small cluster of four malformed newborns of Danish physiotherapists exposed to RFR during pregnancy [Larsen (1991)], conducted a study to determine possible reproductive hazards among female physiotherapists from RFR-exposure. The subjects were members of the Union of Danish Physiotherapists (UDP) born after 1932 and registered with the UDP in 1978 or later who delivered or miscarried between 1978 and 1985. They were identified by linkage of the UDP file to the Danish register of births and medical registers of abortions. The information gathered consisted of all spontaneous abortions treated in hospitals and all deliveries during that period, and included data on induced abortions, gestation durations, births, birthweights, gender, perinatal deaths, places of birth, and mothers' ages. Twins and induced abortions were excluded from the study.

One of the authors interviewed the subjects by telephone about exposure to RFR during pregnancy and about confounding factors without prior knowledge of the outcome of the pregnancies. The only pregnancy-outcome datum obtained

from the interviews was the "time to pregnancy" (the time from the last use of contraception to first recognition of pregnancy). However, information was gathered on some potential confounders, notably the consumption of medicine, tobacco, and alcohol during pregnancy, and serious acute or chronic diseases during pregnancy.

The cases studied consisted of five overlapping groups: (i) spontaneous abortion before the 29th week, (ii) subfecundity (waiting time to pregnancy exceeding six months), (iii) low birthweight (<2500 g), (iv) prematurity (birth before the 38th week), and (v) stillbirth or death within the first year. The reference group for the first case group consisted of a random sample of all births, and the reference group for the other four case groups was the same sample minus any actual cases.

Exposures during the first month of pregnancy were assessed based on two categories: (1) from the main work tasks during the day: manual physiotherapy, electrotherapy (ultrasound, short-wave diathermy), administrative work, and teaching; (2) characterizing the exposure to high-frequency electromagnetic radiation (use of different types of electrodes, time spent in the short-wave room, frequency of short-wave use in the clinic, and direct versus indirect exposure, with indirect exposure defined as for a woman within 1 meter from a diathermy unit operated by a colleague). The emission from the electrodes were scored as: 0 for circuplode- or no exposure, 1 for diplode exposure, and 10 for plate-electrode exposure. Independently of the data analysis, a time-weighted exposure index was formed *a priori* from the product of the score for the electrodes used, frequency of short-wave use, and total time spent in the short-wave room. The index was divided arbitrarily into three categories: 0 for no exposure, 1 for low exposure, and 2 for high exposure.

The major positive finding was an unexpected low ratio of boys to girls for those physiotherapists exposed to high-frequency radiation. Specifically, there were 107 boys and 71 girls born to physiotherapists in category 0; the OR was said to be 1.0 relative to the reference sample (a nonsignificant difference). However, 11 boys and 23 girls were born to the category-1 physiotherapists; the OR was 3.2 with a CI of 1.5-7.1. Also, 4 boys and 13 girls were born to the physiotherapists in category 2; the OR was 4.9 with a CI of 1.6-7.9. The latter two ORs were significant. The authors noted that there was a difference in the male/female gender ratio between the study base (52.6/47.4 = 1.11) and the general population (51.4/48.6 = 1.06), but that the decrease in gender ratio would still be significant.

The results for spontaneous abortions, subfecundity, stillbirth or death within one year, prematurity, and low birthweight yielded ORs nonsignificantly different from 1.0. The possible confounding factors cited above apparently did not contribute to the findings of this study.

It is noteworthy that the data on gender ratio indicated sensitivity to the type of electrodes used: the OR was 2.1 with a CI of 0.6-7.5 for exposure with diplode electrodes, and 2.8 with a CI of 1.5-5.5 for plate electrodes. Also, the type of exposure was important: the OR for direct exposure solely was 2.2 with a CI of 0.9-5.6, but was 2.8 with a CI of 1.0-8.5 for indirect exposure.

The statistical treatments of the data in this study were extensive, but as with other epidemiologic studies, the absence of measurements of the actual

RFR levels to which the physiotherapists were exposed and the vague estimates of exposure durations vitiate the credibility of the single positive finding, as well as the negative findings. In addition, as remarked by the authors, the results are based on sparse data and must be interpreted with caution.

Ouellet-Hellstrom and Stewart (1993) mailed questionnaires to 42,403 female physical therapists in 1989 whose names were obtained from the American Physical Therapy Association, to assess for possible effects of occupational use of microwave and shortwave diathermy at conception time, and specifically whether an excess risk of miscarriage was associated with exposure to RF and microwave radiation just before conception or during the first trimester of pregnancy. Information was sought on infertility, use of oral contraceptives, smoking during pregnancy, and outcome of all pregnancies, the latter including questions on any birth conditions diagnosed during the first 5 years of life and any cancers ever diagnosed. Also sought was information about the age and race of the women. Complete information was requested only from women who had ever tried to or did become pregnant.

Questions regarding occupational exposures included: a complete work history (employer, date of employment, position held), use of therapeutic treatment modalities in general, and use of various modalities and chemicals during the first two trimesters of pregnancy. For each reported occupation, precoded responses were used to elicit information on the frequency of usage of specific treatment modalities (infrared radiation, whirlpool, Hubbard tank, electrical stimulation, transcutaneous nerve stimulation, microwave diathermy, shortwave diathermy, and ultrasound). Other questions asked were on the use of electric blankets, the father's occupation, and any health conditions ever diagnosed in the mother.

To ascertain possible response bias and the reasons for nonresponse, an attempt was made to interview a sample of 500 nonrespondents by telephone for data similar to those from the respondents. Also sought was a brief history of their pregnancies, including the total number, the number of live births, the years of first and last births, and the number of pregnancies incurred while working; and the mother's race and date of birth. Of those 500, 259 were reached and agreed to provide data, and 187 of them were regarded as eligible.

A nested case-control design was used. The authors noted that because of resource constraints, only the questionnaires of respondents who reported ever using microwave or shortwave diathermy (6,684 or 57% of the respondents) were completely edited and processed. Also noted was that "ever exposed" does not imply exposure only just prior to or during any one pregnancy, but meant that all women who had ever used such diathermy were included.

All recognized first-trimester miscarriages (except ectopic pregnancies) reported by those 6,684 respondents were defined as case pregnancies (1,791 of 14,989 pregnancies). Excluded were 38 cases for which the mother's date of birth and date of conception or last menstrual period were missing, leaving a total of 1,753 case pregnancies. These cases were matched with 1,753 control pregnancies, selected from all pregnancies irrespective of pregnancy outcome (excluding ectopic pregnancies). The overall mean difference in maternal age at birth between cases and controls was 1.9 ± 5.6 (SD) months and the mean difference between them in the time interval between conception and interview

was 4.4 ± 7.2 months. The authors remarked that some mothers contributed one case pregnancy only and others one control pregnancy only, but that others contributed one case and one control pregnancy, two case pregnancies, two control pregnancies, three or more case pregnancies, or three or more control pregnancies.

Case and control therapists who had not worked during the 6 months prior to and during the first trimester were classified as unexposed. Therapists of each group were classified as exposed if they had been working and reported using microwave or shortwave diathermy during that time interval. The authors noted that most of the therapists had reported using more than one treatment modality on the same job. Specifically, more than 78% of those who had used microwave diathermy and 64% of those who had used shortwave diathermy had reported using at least four other modalities, rendering it impossible to stratify the analyses by the use of a single modality.

The unconditional odds ratios for an association of miscarriage risk and reported exposure to microwave diathermy are shown in Table 8 (adapted from Table 3 of the paper), stratified with respect to the number of reported exposures per month. Of the 1,759 pregnancies in each group, there were 209 cases (11.9%) and 167 controls (9.5%) who had any exposure.

TABLE 8: UNCONDITIONAL ODDS RATIOS FOR AN ASSOCIATION OF MISCARRIAGE RISK AND REPORTED EXPOSURE TO MICROWAVE DIATHERMY

[Ouellet-Hellstrom and Stewart (1993)]

No. of exposures per month	Case pregnancies	Control pregnancies	OR (95% CI)
	All Pregnancies		
0	1,459	1,494	1.00
<5	88	86	1.05 (0.77-1.43)
5-20	72	49	1.50 (1.04-2.17)
>20	45	29	1.59 (0.99-2.55)*
Total no. exposed†	209	167	1.28 (1.02-1.59)
	No Prior Fetal Loss		
0	1,102	1,258	1.00
<5	71	76	1.07 (0.78-1.49)
5-20	58	47	1.41 (0.95-2.09)
>20	34	25	1.55 (0.92-2.61)**
Total no. exposed†	167	151	1.26 (1.00-1.59)

†All exposed women, including those who reported using microwave diathermy at the time of pregnancy but did not report their level of exposure. Exposure status was unknown for 85 cases and 95 controls.
*Chi² test for trend: $p<0.005$.
**Chi² test for trend: $p<0.01$.

The authors remarked that for all pregnancies, the OR increased with the number of exposures and that by the chi² test, the trend was statistically significant. However, the 95% CI for the most exposure durations (more than

20 hours a month) encompassed 1.00, rendering that OR value nonsignificant. In addition, the CI for the cases and controls with less than 5 hours a month encompassed 1.00 as well. For the cases and controls with no previous fetal loss (Table 8), the total OR was 1.26 but all of the CIs encompassed 1.00. The results for exposure to shortwave diathermy were similarly shown in the paper. All of those CIs encompassed 1.00 and the authors found no significant trend with increasing number of exposures. Thus, the authors concluded that the women were at increased risk of miscarriage from reported use of microwave diathermy six months prior to and during the first trimester of pregnancy, but not from shortwave diathermy.

The positive findings of this study are dubious, because the percentages of exposed cases and controls were too small yield much statistical power. Also, no estimates were presented regarding the levels of exposure to the RFR from either of the diathermy modalities. Third, as the authors stated, the use of other modalities by the therapists could not be stratified adequately. This conclusion applies as well to any of the negative findings in this study.

2.3.1 SUMMARY ON RFR AND CONGENITAL ANOMALIES

The findings of the various studies on RFR and congenital anomalies are summarized briefly in Table 9 (A, B, and C).

Authors	Effects Sought or Examined	Exposure Modality	Effects Reported	Notes & Comments
Sigler et al. (1965)	Down's syndrome in children of mothers nonoccupationally exposed to ionizing radiation, and those with occupational fluoroscopic exposure in medical practice.	Exposure of mothers to ionizing radiation and radar exposure of fathers.	The percentage of case mothers who had received fluoroscopy before childbirth was significantly higher than control mothers, but the percentage of case fathers who reported close association with radars was also significantly higher than control fathers.	See Cohen et al. (1977) below.
Cohen et al. (1977)	Down's syndrome. See Sigler et al. (1965).	Radar exposure of fathers.	This study of the larger data base found no association of Down's syndrome with radar exposure of fathers.	These authors augmented the number of matched case-control pairs in Sigler et al. (1965).
Peacock et al. (1971)	Birth defects. The authors examined Alabama-wide birth records by county over a period of 17 months.	Proximity to military bases.	The authors found a higher percentage of newborns with anomalies for the military personnel in the 6 counties surrounding Fort Rucker than for the civilians.	See Burdeshaw and Schaffer (1977) below.
Peacock et al. (1973)	Birth defects. The authors used more accurate data spanning 4 years, and used better statistical treatment.	Proximity to military bases. The authors compared data for military hospitals at Fort Rucker and Eglin AFB with non-radar bases.	Abnormally high anomaly rates were found at Lyster Hospital (within Fort Rucker) and the military hospital at Eglin AFB; the authors associated this finding with radar exposure.	See Burdeshaw and Schaffer (1977) below.
Burdeshaw and Schaffer (1977)	Birth defects. These authors reexamined the original Alabama birth records but compared the data for the 2 counties encompassing Fort Rucker with the other 65 Alabama counties on a score and rank basis rather than by statewide averages.	Proximity to military bases.	The overall anomaly rate was found to be within expectations for hospitals like Lyster; no significant clustering of anomalies was found in the vicinity of the presumed radar sites.	The reported higher incidence of congenital anomalies at Lyster Hospital was found to be attributable to a higher than normal reporting rate of one physician who apparently included "birth defects" not characterized as such by other physicians.

TABLE 9A: RFR AND CONGENITAL ANOMALIES

Authors	Effects Sought or Examined	Exposure Modality	Effects Reported	Notes & Comments
Källén et al. (1982)	Perinatal mortality and birth defects in infants of female physiotherapists in Sweden.	Occupational exposure of physiotherapists to various treatment modalities.	For the total cohort, the expectation values for all of the endpoints were statistically better or comparable to those for the general population, a finding the authors hypothesized as a "healthy worker" effect. In a case-control study within the cohort, the authors matched two normal infants with each dead or malformed infant, and estimated the exposures of the mothers to various occupational modalities from their responses to a questionnaire. The only possible association with RFR-exposure was authors' report that the use of shortwave equipment was higher by mothers of a dead or malformed infant.	The shortwave-equipment finding was of borderline statistical significance. However, use of responses to a questionnaire is questionable because of self-selection by the respondents. Thus, the finding above is of doubtful validity.
Taskinen et al. (1990)	Spontaneous abortions or birth defects in infants of Finnish physiotherapists.	Patient treatments with ultrasound (0.5-3 MHz); "deep-heat therapy" (including "shortwaves" [27.12 MHz] and "microwaves" [not characterized]; electric-current modalities; and physical exertion.	Significant increases of spontaneous-abortion risk were found for: ultrasound use more than 20 hours a week, electric-current therapies more than 5 hours a week, and heavy lifting or frequent transfers of patients. No significant risk increase of spontaneous abortion was found for deep-heat therapies (shortwaves or microwaves). Regarding congenital malformations, a significant risk increase was reported for deep-heat therapies for 1-4 hours per week but not for 5 or more hours a week, results likely due to selective recall bias.	Statistical treatment of the response data was reasonably extensive, but absent were any data on exposure levels to the various treatment modalities and their variations with time and patient-treatment site. Thus, at least with regard to RFR, little if any credence can be given to either the positive or negative findings of this study.
Larsen et al. (1991)	Possible reproductive hazards among female physiotherapists in the Union of Danish Physiotherapists from RFR-exposure.	Exposures to short-wave diathermy (and to ultrasound and the performance of other duties) during the first pregnancy month were assessed, and an *a priori* diathermy-exposure index was formed.	Data for 1978-1985 on spontaneous abortions, gestation durations, low birth weights, premature births, stillbirths, gender, and deaths within 1 year were analyzed. Twins and induced abortions were excluded from the study. The odds ratios for "subfecundity" (waiting time to pregnancy more than six months), spontaneous abortion, still-birth or death within 1 year, premature birth, and low birth weight did not differ significantly from 1.0. The sole positive finding was a low ratio of boys to girls for those presumed exposed to RFR from diathermy.	As with other epidemiologic studies, lack of measurements of the RFR-exposure levels and vague estimates of exposure durations diminish the credibility of the single positive finding, as well as of the negative findings. Moreover, as noted by the authors, the results are based on sparse data and must be interpreted with caution.

TABLE 9B: RFR AND CONGENITAL ANOMALIES (CONTINUED)

Authors	Effects Sought or Examined	Exposure Modality	Effects Reported	Notes & Comments
Ouellet-Hellstrom and Stewart (1993)	Possible reproductive hazards among female physiotherapists listed in 1989 by the American Physical Therapy Association from occupational use of microwave or shortwave diathermy.	Exposures from treating patients with microwave or shortwave diathermy of frequencies not stated and from use of other modalities and chemicals, just before or during the first trimester of pregnancy.	Tabulated were the odds ratios (ORs) and 95% confidence intervals (CIs) for an association of miscarriage risk and exposure to microwave and shortwave diathermy. For microwaves, 209 of 1,759 (11.9%) case pregnancies and 167 of 1,759 (9.5%) control pregnancies had any exposure. Those data were shown in terms of <5, 5-20, and >20 exposures a month. The respective ORs and CIs were 1.07 (0.77-1.43), 1.41 (1.04-2.17), and 1.55 (0.99-2.55), for overall values of 1.28 (1.02-1.59). The authors stated that by the chi^2 test, the trend in OR increase with exposure was significant ($p<0.005$). However, the CI for the most exposure durations (more than 20 hours a month) encompassed 1.00, rendering that OR value nonsignificant. Similar results were displayed for 167/1102 cases and 151/1258 controls who had no prior fetal losses. For shortwaves, all of the CIs spanned 1.00, with no significant trend with increasing exposure. Thus, the authors concluded that women were at higher miscarriage risk from administering microwave diathermy during their first trimester of pregnancy, but not from shortwave diathermy.	Of 6,684 respondents to mailed questionnaires, 1,753 case pregnancies were selected from those who had first-trimester miscarriages. Those cases were matched with 1,753 control pregnancies selected from all pregnancies irrespective of outcome. Some of the women selected had reported only 1 case pregnancy and others only 1 control pregnancy, but still others contributed 1 each case and control pregnancy, 2 case pregnancies, 2 control pregnancies, 3 or more case pregnancies, or 3 or more control pregnancies. The positive findings of this study are dubious, because the percentages of exposed cases and controls were too small yield much statistical power. Second, the authors gave no estimations on RFR-exposure levels for either of the diathermy modalities. Third, as the authors stated, the use of other modalities could not be stratified adequately. This conclusion applies as well to any of the negative findings in this study.

TABLE 9C: RFR AND CONGENITAL ANOMALIES (CONCLUDED)

2.3.2 CONCLUSION

Although Sigler et al. (1965) had reported finding an association of Down's syndrome in children with RFR-exposure of the fathers, a study by Cohen et al. (1977) of a larger data base did not confirm that association. Peacock et al. (1971, 1973) had reported the incidence of a higher percentage of neonates with anomalies for military personnel at "radar" bases than at non-radar bases, but a more encompassing study and use of a better statistical treatment by Burdeshaw and Schaffer (1977) failed to confirm that finding.

It is noteworthy that in a study by Källén et al. (1982) of infants of Swedish physiotherapists, the authors had found better outcomes on all of the endpoints for their exposed cohort than their controls, which they ascribed to a "healthy worker" effect. On the other hand, they also noted that the use of shortwave equipment was higher by mothers of a dead or malformed infant, but that finding was of borderline statistical significance and otherwise open to serious question. Taskinen et al. (1990) sought possible increases in risk of spontaneous abortion or congenital abnormalities for physiotherapists who treated patients with various modalities, including "shortwaves" (27.12 MHz) and "microwaves" (frequencies or other characteristics not indicated) yielded mixed findings, but little if any credence can be accorded either the negative or positive findings because of lack of quantitative exposure data and the likelihood of recall bias in the responses to questionnaires. A study by Larsen et al. (1991) of pregnancy outcomes of Danish physiotherapists yielded only one positive finding, a lower than expected ratio of neonate boys to girls, but the data were sparse and the descriptions of the exposures to short-wave (diathermy) RFR were vague. Ouellet-Hellstrom and Stewart (1993) studied pregnancy outcomes of physiotherapists, listed in 1989 by the American Physical Therapy Association, who treated patients with microwave or shortwave diathermy (or other modalities) just before or during the first trimester of pregnancy of the therapists. The authors reported a trend toward increasing risk of miscarriage with frequency of microwave-diathermy use, but no such trend for shortwave-diathermy use. However, both the positive and negative findings of this study are dubious, because of the small numbers of cases involved, the absence of any information on the RFR frequencies or exposure levels, and the inability to separate the effects of the various modalities from one another. It is noteworthy that the findings of Ouellet-Hellstrom and Stewart (1993) of a significant trend of increasing risk for those who used microwave diathermy and no such trend for shortwave diathermy are opposite to the findings of Källén et al. (1982).

Thus, collectively those studies provide no scientifically credible evidence that chronic exposure of mothers during pregnancy or of fathers to RFR at levels at or below the ANSI/IEEE (1992) maximum exposure guidelines would cause any anomalies in their offspring.

2.4 RFR AND OCULAR CHANGES

The cornea and lens are the regions of the eye most vulnerable to RFR at high levels by their surface location and because heat produced by the RFR is more effectively removed from other eye regions by blood circulation. Indeed, cases of ocular damage in humans ascribed to occupational exposure to RFR have been reported (e.g., Hirsch and Parker, 1952; Shimkovich and Shilyaev, 1959; Kurz and Einaugler 1968; Zaret, 1969; and Issel and Emmerlich, 1981). The

exposure histories of these individuals could not be ascertained with any degree of certitude, but it is likely that their actual or incipient vision impairment resulted from exposure to average power densities substantially greater than the threshold found in animal studies (about 150 mW/cm^2).

Cleary et al. (1965) performed a retrospective study of the incidence of cataracts in Army and Air Force veterans of World War II and the Korean War to determine whether such incidence could have been related to occupational RFR-exposure. A preliminary study had indicated that a sample of about 2,500 cataract cases and a control group of the same size would be sufficient to permit detection of a twofold increase in relative risk with a probability of 80% at the 5% significance level. Veterans Administration hospital records yielded a total of 2,946 Army and Air Force veterans born after 1910 who had been treated for cataracts during the period 1950-1962. The authors used military occupational specialties (MOSs) to classify each veteran as a radar worker, a nonradar worker, or one whose specialty could not be discerned. (Naval veterans were excluded because MOSs were not available.) Of the 2,946 veterans, 2,648 were Army veterans, 96 were Air Force veterans, and 202 had MOSs that did not permit determination of occupational category. Randomly selected as controls were 2,164 veterans hospitalized during the same period for other ailments (1,910 Army, 129 Air Force, and 125 MOSs that did not permit determination of occupational category).

In the radar group, they found only 19 persons with cataracts, 2,625 persons without cataracts, and 100 persons with uncertain occupations. In the control group, only 21 had cataracts, 1,935 did not, and the occupations of remaining 83 persons were uncertain. Evidently, at the outset, the small numbers of persons with cataracts in both groups yielded no basis for an association between RFR-exposure and cataract causation. The authors noted that the overall relative risk factor was 0.67, as compared with 1.0 for no increase in relative risk and with values exceeding 1.0 indicating the degree of severity of the effect. They also noted that examination of the Air Force data separately yielded a risk factor of 2.18, but with a significance level that exceeded 10%, and they indicated that the number of cases was too small to draw any inferences. They stated that an analysis of all the data by age grouping suggested no alteration in age-specific incidence of cataracts due to RFR-exposure.

Cleary and Pasternack (1966) analyzed the responses to a questionnaire on the occupational histories of personnel then currently employed at 16 microwave installations, and used the histories to differentiate controls from exposure cases. They thereby selected 736 workers as occupationally exposed to RFR and 559 workers from the same locations and occupational environments (other than RFR) as controls. Exposure cases were grouped into occupational specialties by considering the types and functions of equipments used and the average generated powers, RFR frequencies, and methods of power termination. Exposure severity was classified by considering duration of work with each type of equipment, working distance from the equipment during normal operation, and specific type of work performed. The authors then derived relative exposure scores by assigning appropriate weights to those factors (for example, proportionality to average power and inverse proportionality to equipment distance).

Histograms representing the age distribution (for the 5-year intervals from 16 to 65 years) were presented for each group. The mean ages for the

exposed and control groups were 32.76 and 33.20 years, respectively; however, the exposed group had a relative maximum of 25% in age subgroup 26-30 years, whereas the control group had a relative maximum of 19% in age subgroup 21-25 years and a larger proportion of older workers than the exposed group. A chi-square analysis by the authors confirmed that the age-composition difference between the two groups was significant, and they noted that "man-for-man age matching of exposed and controls would have eliminated age differences but, due to sampling restrictions, this was not possible."

Also presented for the exposed group were histograms representing the age distribution of relative exposure scores (ranging from 1 to 85 in 5-point intervals) and the age distribution of exposure durations (ranging from 0 to 299 months in 20-month intervals). The first histogram indicated that the largest number of workers, 36%, had exposure scores in the 6-10 interval, with a sharp falloff to about 2% for exposure scores in the 31-35 interval. The other histogram showed that the largest number of workers, 20%, were exposed for durations in the range 0-19 months, with an approximately linear decrease to about 2% for exposures in the range 140-159 months.

The persons in both groups were examined with a slit lamp, and each person was graded (on a double-blind basis) for subcataractous lens changes, classified as minute defects, opacification, reluctency, sutural defects, and posterior polar defects. A grade ranging from 0 for "insignificant" to 3 for "large numbers or major degree of change (short of clinically recognized cataract)" was assigned to each lens in each category of lens defect. The "eye score" was defined as the unweighted sum of the scores for each type of defect.

A linear regression model was used for each group to relate mean eye score to age on the basis that the major increase in eye score with time was due to physiological aging of the lens. The slope of the regression line for the exposed group was significantly higher than for the control group; the two lines crossed at age 20 years, at which the mean eye score was 4.2. However, the authors remarked that no detrimental effects, such as a loss of visual acuity or higher propensity for cataract formation, were associated with the observed subclinical eye changes in the exposed group, and that those results may indicate an acceleration of aging of lens tissue. The authors then added terms for exposure score, duration, and duration-exposure interaction to the linear regression equations, and found significant ($p<0.05$) differences in the regression coefficients, with age providing the highest contributions to eye score and successively smaller contributions from the other terms.

The authors then used a 2x4 contingency chi-square table to determine which of the lens-defect categories contributed substantially to the scores. The highest mean scores were for minute defects, 1.66 and 1.61 for the exposed and control groups, respectively, but the difference was nonsignificant. The mean scores for opacification were 1.58 and 1.47, respectively, a significant difference ($p<0.025$). The mean scores for relucency were 1.56 and 1.53, and those for sutural defects were 1.19 and 1.21, but both differences were not significant. The lowest mean scores were for posterior polar defects, 0.62 and 0.41 respectively for the exposed and control groups, but the difference between them had the highest significance level ($p<0.0005$).

Open to question in this study, in addition to the usual uncertainties about actual exposure frequencies, levels, and durations, were the grading of

each worker for lens changes on an arbitrary 0-3 scale and use of composite eye scores, measures that were subjective and not associated with actual reduction in visual acuity in the individuals examined; statistical analyses based on such measures can be misleading. Other problems were the previously noted significant difference in age distribution between exposed and control groups and the age-related lens changes in both. Regarding the latter, the authors stated: "Since the number of defects increased significantly with age in the control group as well as in the group of microwave workers, this process may be interpreted as indicating lens aging. Occupational exposure to microwave radiation may be implicated as a stress which increases the rate of lens aging although it is impossible at present to relate this effect to functional impairment such as loss of visual acuity or cataracts."

Aurell and Tengroth (1973) investigated 98 personnel involved in the industrial development of radar equipment (presumably in Sweden). Of those, 68 were exposed to microwaves (unspecified frequencies, levels, or durations), comprising persons testing radar equipment and measuring microwave radiations from various klystrons, and the remaining 30 persons from the experimental laboratories. The control group consisted of 30 people from the same industry who had never been exposed as far as known. Two eye specialists independently examined the 98 exposed people and the 30 controls without knowledge of their occupation or exposure. The examination included refraction and determination of visual acuity, a study of the optical media with a corneal microscope and slit lamp under complete pupil dilation, and an ophthalmoscopic study of the retina.

The numbers of persons who had opacities larger than 0.5 mm in diameter or a large concentration of smaller opacities in the subcortical region were displayed as bar graphs for those less than 26 years of age and for the 5-year age subgroups 26-30 to 56-60 years. Of those younger than 26 years, none of the 6 persons in the exposed group and none of the 7 persons in the control group had opacities as defined above. In the subgroup 26-30 years of age, 6 of the 20 exposed persons and 2 of the 15 controls had opacities. In the subgroup 31-35 years of age, 5 of the 14 exposed persons and none of the 4 controls had such opacities. Of those 36-40 years of age, 6 of the 15 exposed persons and 1 of the 2 controls had opacities. Of 8 persons in the age group 41-45 years, 2 of the 6 exposed had opacities, but neither of the 2 control persons did. Two of the 3 exposed persons 46-50 years old, 2 of the 3 exposed persons 51-55 years old, and the one exposed person in the 56-60 age range of exposed persons had opacities, but there were no persons older than 41 years in the control group for comparison.

The retinal examinations were of the central region of the fundus, and lesions resembling chorioretinal scars after inflamatory reactions were sought. The results were qualitatively similar to those for opacities: 19 of the 68 exposed people exhibited such lesions, as compared with only 1 of the 30 in the control group. In their discussion, the authors noted that in two of the exposed cases, the lesions resulted in a decrease in vision, but that no comparable loss of vision was evident for those with the opacities.

The authors remarked: "It is of great interest that eye lesions, both lenticular and retinal, found in this material are significantly higher in the group of persons belonging to the test group than the persons working in the laboratories. It is difficult to draw conclusions as to which kind of work

entails the most risk, but one knows that the personnel testing the equipment for measuring radiation are more liable to exposure from higher power levels than others, i.e. laboratory personnel...Another explanation is that the eye lesions observed are due to leakages from the equipment, or carelessness on the part of the personnel."

They also stated: "The pathogenesis behind the retinal lesions is very obscure. The transmission properties of microwaves in biological tissue do not explain why certain areas in the retina should be changed as a result of thermal effects. The change in dielectric constants in the different layers of the retina might give an increase in intensity of 3 to 4 times in the layers but this seems too slight to explain the damage." They also remarked that the mechanisms for the observed ocular effects, including the possibility of a nonthermal basis, are unknown.

It is difficult to lend much credence to the findings of this study, because of the small numbers of persons in each 5-year-age subgroup and the absence of control persons older than 41 years. About the latter, the authors stated: "In the higher age group--over 41 years--it is impossible to separate lens opacities due to microwave exposure from a senile cataract because no controls older than 41 years were examined." Also, they noted that the numbers of eye lesions were significantly higher in the personnel testing radar equipment or measuring microwave radiations than in the laboratory personnel, but did not describe the differences in the kinds of tasks performed by the two groups; any significant exposure differences between those groups might have been clarified by representative measurements of exposure levels and estimates of exposure durations for both kinds of tasks.

Appleton and coworkers initiated surveys in which they examined the eyes of personnel at Army posts where various types of electronic communication, detection, guidance, and weather equipment were under development, test, and use. In Appleton and McCrossan (1972), the results of semiannual examinations conducted between November 1968 and May 1971 of 226 persons employed at Fort Monmouth, New Jersey, were presented. Personnel selection was based on the Occupational Vision Program of that post, and all personnel with histories of working with microwave equipment, lasers, xenon arcs, ultraviolet, and welding were asked to participate. Ophthalmologists conducted the examinations without prior knowledge of the histories of the individuals. First, they determined the visual acuity of each person. Then they dilated the pupil of each eye and examined the fundus by direct ophthalmoscopy, with special attention on the details of the posterior pole. Following this, they examined the anterior segment with a slit lamp that had a beam-splitter and attached observation tube. Recorded were:

1. Presence or absence of opacities visible as shadows against the red reflex seen in the coaxial view (lighting and viewing lines coincident). If present, the number, location, and shape of the opacities were noted.

2. Presence or absence of vacuoles. If present, their number and location were noted.

3. Presence or absence of posterior subcapsular iridescence (PSCI), a polychromatic luster caused by interference patterns at the level of the posterior lens shagreen when the angles of illumination and viewing are equal with respect to the normal line for the region where the sutures meet and in the same horizontal plane as this line.

4. Absence of all of the foregoing, results termed "negative".

Following the examinations, the population was divided on the basis of microwave history. The individuals who provided histories of working directly with microwaves, either as test-development personnel or as operators of such equipment comprised the experimental group (91 persons). The control group comprised those employed at the Army post but who denied ever having worked with or being near such equipment (135 persons). Each group was divided into 5 subgroups for the 10-year age spans 20-29 through 60-69 years; the size of each subgroup and the number of persons therein in each of the 4 examination categories above are shown in Table 10 (adapted from Tables 1 and 2 of the paper). Some persons qualified and were counted in more than one category.

TABLE 10: RESULTS OF APPLETON AND McCROSSAN (1972)

EXPERIMENTAL GROUP

Age	Size	Opacities	Vacuoles	PSCI	Negative
20-29	15	0 (0%)	2 (13%)	3 (20%)	11 (73%)
30-39	21	5 (24%)	7 (33%)	5 (24%)	11 (52%
40-49	31	10 (32%)	8 (26%)	17 (55%)	9 (29%)
50-59	18	7 (39%)	4 (22%)	13 (72%)	3 (17%)
60-69	6	4 (67%)	3 (50%)	4 (67%)	0 (0%)

CONTROL GROUP

Age	Size	Opacities	Vacuoles	PSCI	Negative
20-29	37	0 (0%)	4 (11%)	9 (24%)	25 (68%)
30-39	32	6 (19%)	6 (19%)	10 (31%)	15 (47%)
40-49	38	10 (26%)	10 (26%)	21 (55%)	9 (24%)
50-59	20	6 (30%)	7 (35%)	17 (85%)	6 (30%)
60-69	8	1 (13%)	2 (25%)	4 (50%)	3 (38%)

In the four categories above, comparisons of corresponding experimental and control age subgroups show several higher percentages, several lower percentages, and several with no difference. Particularly noteworthy are the larger percentages of negative results for the three younger subgroups (20 to 49 years old) of the experimental group than in the corresponding subgroups of the control group, and the converse for the two older subgroups (50-69 years old). No statistical treatment was presented, rendering it difficult to assess whether the differences were significant and if so, whether they were related to RFR-exposure. However, the authors did conclude:

"It appears from this study that available clinical evidence does not support the assumption that cataracts which develop in personnel performing duties in the vicinity of microwave generating equipment are a result of microwave exposure, unless a specific instance of severe exposure can be documented and correlated with subsequent cataract development."

In a later paper, Appleton (1973) elaborated on the selection and use, by ophthalmologists, of opacities, vacuoles, and PSCI as easily recognizable measures or diagnostic criteria of possible subclinical eye damage, and noted that one or more of these signs are seen more often in people as they age and

in younger persons who are developing cataracts. The same Fort Monmouth data (with a few minor discrepancies) were presented. Added to those data were the results for personnel at White Sands Missile Range, NM, and Fort Bliss, TX, and those subsequently obtained for personnel at Tobyhanna Depot, PA, and Fort Huachuca, AZ, which yielded pooled totals of 605 experimental and 493 control personnel. The findings for the larger data base were basically similar to those of the previous survey.

Final results of the survey were presented in Appleton et al. (1975b), which encompassed 1542 experimental and 801 control subjects at the posts noted above, who were examined semiannually over the period from November 1968 to September 1973 and included persons less than 20 years old. Those results are reproduced in Table 11 (adapted from Tables 1 and 2 of the paper). The authors did not present results in the negative category.

TABLE 11: RESULTS OF APPLETON ET AL. (1975b)

Age	Size	Opacities	Vacuoles	PSCI
		EXPERIMENTAL GROUP		
<20	43	1 (2%)	4 (9%)	8 (19%)
20-29	506	17 (3%)	94 (19%)	163 (32%)
30-39	433	44 (10%)	102 (24%)	180 (42%)
40-49	316	37 (12%)	108 (35%)	188 (60%)
50-59	196	45 (23%)	66 (34%)	132 (68%)
60-69	48	15 (31%)	16 (33%)	16 (33%)
		CONTROL GROUP		
<20	13	0 (0%)	1 (8%)	1 (8%)
20-29	188	10 (5%)	33 (18%)	53 (28%)
30-39	196	21 (10%)	55 (28%)	99 (51%)
40-49	247	37 (15%)	71 (29%)	138 (56%)
50-59	128	25 (20%)	53 (41%)	95 (74%)
60-69	29	8 (28%)	14 (48%)	20 (69%)

The authors stated: "The conclusions that can be drawn from such a survey are necessarily limited: if any population has been partitioned on the basis of some possible occupational exposure and the health of the `target' group is the same as the `control' group (a negative result), then it is reasonable to conclude that the occupational exposure (if any) has been insufficient to affect health. On the other hand, if there is a difference between the two groups with respect to health, this difference may be due to the exposure, or it may be due to some other variable, known or unknown; so the only conclusion that could be drawn in that second case would be that harmful effects of occupational exposure have not been ruled out."

They concluded: "The results of the survey described here can be considered as showing no difference between the two groups (a negative result); so it is reasonable to conclude that lens damage due to microwave radiation from military equipment has not occurred."

Shacklett et al. (1975) performed a study of 477 military personnel and civilians of known histories of working around microwave-generating equipment

at eight Air Force bases, and 340 age-matched control persons, with care taken to eliminate any individual with a then current or past history of work with microwave-generating equipment. Either the presence of ocular effects or their absence was recorded, based on the following criteria (similar to those used by Appleton and coworkers:

1. Opacities visible against the red reflex of the slit lamp at 6x or 10x.
2. Vacuoles visible against the red reflex of the slit lamp at 6x or 10x.
3. Posterior subcapsular iridescence (PSCI).

The investigators secured detailed work histories of the individuals, the types of microwave equipment involved, and times spent working around each type. They also obtained past medical histories of the subjects and their families, in a search for evidence of ocular diseases or incidents, such as diabetes mellitus, chronic uveitis, trauma, and/or exposure to ionizing radiation. The subjects were examined by a team of ophthalmologists who had no knowledge of their histories or to which group they belonged. The results for the exposed and control groups are shown in Table 12 (adapted from Tables I and II of the paper).

TABLE 12: RESULTS OF SHACKLETT ET AL. (1975)

Age	Total	Opacities	Vacuoles	PSCI
EXPOSED GROUP				
<20	4	2 (50%)	1 (25%)	1 (25%)
20-29	150	82 (55%)	58 (39%)	62 (41%)
30-39	220	136 (62%)	83 (38%)	148 (67%)
40-49	79	35 (44%)	38 (48%)	57 (72%)
50-59	21	11 (52%)	12 (57%)	17 (81%)
>59	3	2 (67%)	2 (67%)	3 (100%)
Totals	477	268 (56%)	194 (41%)	288 (60%)
CONTROL GROUP				
<20	9	4 (44%)	5 (56%)	3 (33%)
20-29	115	62 (54%)	39 (34%)	58 (50%)
30-39	128	79 (62%)	54 (42%)	92 (72%)
40-49	55	37 (67%)	24 (44%)	35 (64%)
50-59	27	17 (63%)	15 (56%)	19 (70%)
>59	6	4 (67%)	2 (33%)	5 (83%)
Totals	340	203 (60%)	139 (41%)	212 (62%)

The results showed surprisingly high percentages of all three criteria in each age group for both the exposed and control groups, with a trend toward increases with age, but no significant RFR-related differences. The authors noted the observation of ophthalmologists that "numerous opacities in some lenses are completely innocuous, neither causing visual impairment nor showing progression," so they used the terms "clinically significant" or "clinically insignificant" as "inexact" descriptors.

Using those terms, eight of the 447 exposed subjects and four of the 340 controls had clinically significant lens changes, a difference appearing to be significant. However, three of the exposed subjects had family histories for cataracts and/or diabetes mellitus, one had a family history for myopia and keratoconus [noninflammatory protrusion of the cornea], and the family of another had corneal disease that required penetrating keratoplasty [corneal transplant]. Of the other three exposed subjects, one had been discharged from the military for rheumatoid arthritis that required treatment with systemic corticosteroids for at least 4 years; one had medically significant lens changes in only one eye, but with a history of beta [ionizing] radiation of that eye for recurrent pterygium [an abnormal triangular fold of membrane extending from the conjunctiva to the cornea]; and the third was recorded as having "perhaps significant lens changes". The authors concluded that the lens changes in the exposed and control groups were related to age and not with RFR-exposure.

Frey (1985) took issue with the findings of Appleton and McCrossan (1972) and cited "three major flaws":

"First, the exposed group likely included persons with little or no exposure. This mixing in the sample they selected as the exposed group would tend to minimize the possibility of finding microwave effects. Secondly, their control group consisted of people working with equipment known to cause eye damage, a factor that would also tend to minimize the possibility of finding microwave effects. Thirdly, and most important, they did not do a statistical analysis on their data. When the writer [Frey] did one, it showed that Appleton and McCrossan had a statistically significant difference between groups, with the microwave exposed group showing more lens opacities than would be expected by chance."

About the first two points above, Frey (1985) reproduced the percentages of opacities by age subgroup found by Appleton and McCrossan (1972) in the exposure and control groups and for comparison, presented the percentages of cataracts in males published by the National Center for Health Statistics. Both sets of percentages are displayed in columns 2-4 of Table 13, with the Appleton and McCrossan control and experimental percentages denoted "A&M-Controls" and "A&M-Exposed," respectively, and those for the National Center for Health Statistics survey as "NCHS".

TABLE 13: PERCENTAGES OF OPACITIES
[Frey (1985)]

Age	A&M-Controls	NCHS	A&M-Exposed	A-Controls
20-29	0	2	0	5
30-39	19	2	24	10
40-49	26	6	32	15
50-59	30	16	39	20
60-69	13	34	67	28

Frey commented that the differences in percentages in the Appleton and McCrossan control group relative to those for the NCHS survey were indicative of the bias in the control group, because some of the persons in the latter group had worked with equipment known to damage the eye. Not clear, however,

was why Frey (1985) chose to analyze that earlier study rather than the final results in Appleton et al. (1975b), of which he evidently was aware, and which encompassed much larger experimental and control groups; instead, he merely dismissed the later study as "also flawed". The percentages of opacities in the control group of the Appleton et al. (1975b) study [Table 11] are shown under "A-Controls" in column 5 of Table 13. These percentages are closer to those for the NCHS survey than the corresponding values for the A&M-Controls, thus invalidating that Frey argument.

Regarding the statistical significance of the Appleton and McCrossan (1972) data, Frey (1985) indicated that he had performed a Kilmogorov-Smirnov test and found that the differences in opacity percentages were not related to a difference in age distribution between groups. He then counted all persons (without regard to age subgroup) reported by Appleton and McCrossan as having opacities: respectively 26 and 23 individuals in the experimental and control groups, and all who did not have opacities (including those reported to have vacuoles and/or exhibiting PSCI): 65 and 112 persons, respectively. To test the hypothesis that exposure to microwaves increases opacities, he performed a chi-square test on those four numbers and obtained 4.2, $p<0.05$.

In a response to Frey (1985), Wike and Martin (1985) noted that Frey's comparison of percentages of opacities with the NCHS percentages of cataracts was inappropriate because opacities and cataracts are not identical and that Appleton and coworkers "deliberately used three reliable physical signs (opacities, vacuoles, and posterior subcapsular iridescence) of developing cataracts rather than the diagnosis of cataract because ophthalmologists cannot agree on the diagnosis of cataract except in fully matured cases."

Wike and Martin (1985) noted that Appleton and coworkers did not provide any information about the characteristics of their subjects except for their age ranges, and that their conclusions rest on the validity of the assumption that the two groups were equivalent in other subject characteristics, such as diet, exercise, general health, etc., an assumption challenged by Frey. Wike and Martin stated: "Frey's logic is puzzling. If he deemed the design [of the Appleton survey] to be inadequate, then why should the data be analyzed?"

About Frey's statistical analysis, Wike and Martin (1985) stated four major reservations: First, they cited Chapter 10 of Fleiss (1973), who listed the method [used by Frey] of performing a chi-square test on a table of totals under "Methods to be Avoided," and gave an example in which two nonsignificant chi-square tables that produced a significant chi-square table when combined. Second, regarding Frey's dismissal of the Appleton et al. (1975b) study, they indicated that if Frey had analyzed it (which included the results of Appleton and McCrossan, 1972), he would have obtained 2.82, $p=0.09$ (a nonsignificant result).

Third, Wike and Martin (1985) noted that Frey had not analyzed the data on vacuoles or PSCI. They remarked that if Frey had applied his chi-square method to the vacuole and PSCI data in Appleton and McCrossan (1972), he would have found that the differences between experimental and control groups were nonsignificant for either response; for the data in Appleton et al. (1975b), the chi-square test would have shown that the proportion of vacuoles were nonsignificantly lower, and the proportion of PSCIs were significantly lower, in the experimental than the control group.

Fourth, Wike and Martin indicated that Frey's analysis of groups was not optimal for the factorial design of the Appleton studies, in which the factors were age (five levels), group (two levels, experimental and control), and opacity response (two levels, presence or absence), and that therefore Frey had learned nothing about the other main effect of age and the interaction of age and group on opacities. Instead, Wike and Martin noted that log-linear analyses for models of various levels of complexity are appropriate and they provided the results of such analyses of the data in Appleton and McCrossan (1972) and Appleton et al. (1975b). The analyses of both sets of data yielded the same conclusions: The occurrence of opacities was significantly associated with age and not with groups, and that Frey's conclusion was erroneous.

Zaret (1974) described a case of a housewife who reported in 1961 (at age 39 years) that her near vision was becoming blurred. Examination by an ophthalmologist at that time showed that other than presbyopia (age-related impairment of vision due to reduction of lens elasticity, yielding loss of accommodation), the cornea, anterior chamber, iris and pupillary reactions, lens, and retina of both eyes were normal; unaided vision was 20/25 for the right eye and 20/20 for the left eye.

At the next examination in 1972, the best acuity in subdued light was 20/70 for the right eye and 20/50 for the left eye. The patient complained about further vision impairment under higher but normal ambient lighting. Her ophthalmologist found extensive posterior subcapsular opacities and a few opacities and vacuoles in the anterior subcapsular areas of both lenses, which were more advanced in the right eye than the left eye. About a month later, she underwent cataract extraction for the right eye, after which its visual acuity was correctable to 20/15.

Use of a microwave oven acquired in 1966 was the suspected cause. In 1971, measurements of that oven by the Radiological Health Division of her home county (Los Angeles) yielded maximum leakage of 2 mW/cm^2 during operation and 40 mW/cm^2 when opening the door. The author of this paper estimated that during the period between oven acquisition and symptom appearance in 1969, the patient had used the oven for a total of about 500 hours and had opened its door about 5,000 times; since then until 1971, when the oven was stated to be faulty by the author, she had used the oven for about 350 hours and had opened the door about 3,500 times.

In 1973, the author (an ophthalmologist) examined the patient and found that visual acuity of the surgically treated right eye was easily correctable to 20/20 for distance and Jaeger 1 print for reading. However, vision in the left eye was 20/80 correctable to a faulty 20/50 and no lens could improve the near vision enough to permit reading of ordinary test print. In addition, the left lens showed an advanced stage of capsular cataract, more in the posterior region than the anterior region. The author also indicated that microwave-induced cataracts are quite distinctive in appearance relative to cataracts from other causes.

Letters of comment by S.M. Michaelson and J. Osepchuk, R.L. Carpenter, G.R. Merriam, D.D. Donaldson, and B. Appleton that took issue with various aspects of the Zaret (1974) paper, and one letter by J.A. Bouchat in support of the author, were appended to the paper together with a letter of responses by Dr. Zaret. Among the major points in contention were the occurrence of

uniquely distinguishable microwave cataracts, that the cataracts seen in the patient were caused by exposure to leakage from the microwave oven, that the oven itself was faulty, and the relevance of the measured leakage levels cited in the Zaret (1974) paper to the intensities and durations of the patient's exposures.

In his letter of support, Prof. Bouchat cited the paper "Cataracte Capsulaire Bilatérale et Radar" by J. Bouchat and C. Marsol (1967) on an association of cataracts with exposure to radar emissions, in which he stated: "As far as the etiology is concerned, nothing in the personal or family history, nothing in the clinical and biologic summary permits one to find an etiology for these cataracts. The only thing that comes to mind is the idea of exposure to nonionizing radiation." He also remarked on the rarity of capsular cataracts and the ease in confusing them with subcapsular cataracts, but suggested alternative interpretations to the ophthalmologic photographs presented in the Zaret (1974) paper.

Most important, perhaps, is the argument that the exposure levels of the patient, however evaluated, were far below the cataractogenesis thresholds found in many experiments with laboratory animals, with no indications of cumulative effects at such low levels.

Hollows and Douglas (1984a) examined the lenses of 53 radiolinemen who were occupationally exposed to RFR by erecting and/or maintaining radio, television, and repeater towers throughout Australia. The subjects included workers who had maximal cumulative RFR-exposure but excluded workers known to have cataracts or who had cataracts removed. The RFR frequencies ranged from 558 kHz to 527 MHz. Measurements of power density in and around work areas yielded values in the range 0.08 mW/cm^2 to 4,000 mW/cm^2.

The results were statistically compared with those for 39 age-matched controls from the same Australian states who had never been radiolinemen. The authors remarked: "For most of the working lives of the radiolinemen in this study there was no national standard for permitted exposure limit...The radio and television towers appear to be the only occupational source of microwaves to which these men were exposed...It was not possible completely to exclude from the control group persons with ocular symptoms that could have related to cataract." All of the subjects were under 60 years old. Each examination was done without prior knowledge of whether the subject was a radiolineman.

The primary ocular finding was "posterior subcapsular cataract (PSC)" in one or both eyes of 11 of the 53 radiolinemen (21%) as compared with 3 of 39 controls (8%); alternatively, PSC was found in 19 of the 106 eyes (18%) of the radiolinemen as compared with 6 of the 78 control eyes (8%). By use of the Freeman-Tukey transformation, the former was nonsignificant (p=0.086) at the 5% level and the latter was barely significant (p=0.043). The mean ages were 46 ± 10 (SD) and 42 ± 9 respectively for the radiolinemen with and without PSC. For the controls with and without PSC, the mean ages were 37 ± 6 and 44 ± 9, respectively.

The authors also reported: "Nuclear sclerosis, a type of lens opacity possibly attributable to exposure to solar irradiation, was present in 50 (47%) of the eyes of radiolinemen (grade 1 in 42, grade 2 in 8) and in 34 (44%) of the eyes of controls (grade 1 in 32, grade 2 in 2) (chi-squared=

2.18; not significant.) Pseudoexfoliation of the lens capsule was not found in either group. Pterygium [an abnormal triangular fold of membrane extending from the conjunctiva to the cornea] occurred four times in the radiolinemen, and once in the non-radiolinemen." The authors suggested that the excess of PSC in radiolinemen may be work-related.

However, the contribution of RFR-exposure to those results is not clear bcause of the reported occurrence of nuclear sclerosis. Also, the authors did not indicate the extent of vision degradation ascribable to PSC and/or nuclear sclerosis. In this context, it is unclear whether "postcapsular cataract" (which was not defined by the authors) is more severe than, or qualitatively differs from, "posterior subcapsular iridescence" (PSCI), one of the three precursors to cataract development described in Appleton and McCrossan (1972).

Hocking (1984) took issue with some aspects of the Hollows and Douglas (1984a) study, specifically about how the 53 subjects were selected from 223 linesmen (comprising only 23%) and why any person with an ocular symptom was excluded. Also noted was that linesmen could also have been exposed to frequencies up to 13 GHz rather than only in the range 558 kHz to 527 MHz, and in the absence of more specific information, surmised that the stated exposure levels may have been based only on E-field measurements in the near field and converted into far-field power densities, thereby would be inaccurate.

Harding (1984) questioned the exposure levels indicated by Hollows and Douglas (1984a), remarking that exposure of the linesmen to 3956 mW/cm² (the maximum level) "would surely cook them".

The Hollows and Douglas (1984b) responses to the comments above included explanations about how the subjects were selected, that the frequencies and power-density measurements had been provided by Dr. Hocking's organization.

Hocking et al. (1988) sought possible effects on the health of nine radiolinemen due to exposure to 4.1-GHz RFR from an open waveguide that was inadvertently activated. The men were divided into a "high-exposure" group comprising two individuals who had been exposed to 4.6 mW/cm² for up to 90 minutes, and a "low-exposure" group comprising the other seven men who had been exposed to less than 0.15 mW/cm². By calculation, upper SAR limits for the skin, pituitary gland, and whole body for the high-exposure group were respectively 3.8, 0.06, and 0.13 W/kg. The range of SAR in their eye lenses was calculated to be 1.2-1.5 W/kg.

Both men in the high-exposure group reported loosening of their scalp hair, beginning about two weeks after exposure and lasting about a month. One of them also claimed temporary sexual impairment and persistent symptoms of insomnia and irritability. The other individual had a moustache that was not affected.

The men in both groups were given medical examinations, their eyes were examined by ophthalmologists periodically for nine months, and blood and semen samples were evaluated. One man in each group showed a significant elevation of creatine phosphokinase. No other significant biochemical or hematologic abnormalities were found in the high-exposure group. Three men in the low-exposure group exhibited mild liver-function abnormalities (ascribed to alcohol consumption).

The authors tabulated the results of the ophthalmic examinations of each subject. In the first post-exposure examination, various eye abnormalities were observed in the men of both groups, but vision was normal in all. In the second post-exposure examination, eye changes were seen in both groups, but the third examination showed no further changes. The authors suggested that the changes could be ascribed to observational differences among the examining ophthalmologists. Their general conclusion was that the slight abnormalities seen in both groups were inconsistent and were unlikely to have been due to the RFR-exposure.

2.4.1 SUMMARY ON RFR AND OCULAR CHANGES

The findings of the various ocular studies of humans are summarized in Table 14 (A, B, C, and D).

Authors	Effects Sought or Examined	Exposure Modality	Effects Reported	Notes & Comments
Cleary et al. (1965)	Analyzed were hospital cases of cataracts in U.S. WW II and Korean War veterans for a possible relationship to RFR-exposure.	Hospital cases with military occupational specialties (MOSs) related to radar were considered to have been RFR-exposed.	In the radar group, there were only 19 persons with cataracts and 2,625 persons without cataracts. In the nonradar group, there were only 21 persons with cataracts and 1,935 without cataracts. Those small percentages yielded no basis for an association between RFR-exposure and cataract causation.	Controls were veterans with non-radar MOSs concurrently hospitalized for ailments other than cataracts.
Cleary and Pasternack (1966)	Ocular effects of exposure at microwave installations based on the responses to a questionnaire. Controls were selected from the responses of personnel in non-RFR occupations at the same places.	The authors derived exposure scores from the equipments used, average powers, RFR frequencies, and exposure durations.	Regression lines were drawn for mean eye score versus age for both groups. The slope of the line for the exposed group was significantly higher than for the control group; the lines crossed at 20 years of age, perhaps indicating an acceleration of aging of lens tissue. However, no detrimental effects on vision were found.	The exposed and control groups were examined with a slit-lens and graded for subcataractous lens changes on a 0-3 scale. Open to question were the use of a subjective scoring scale and a significant difference in age distribution between the groups and the age-related lens changes in both.
Aurell and Tengroth (1973)	RFR-ocular effects in 63 Swedish personnel who tested industrial radar equipment, measured RFR levels from klystrons, or worked in experimental laboratories. The controls were 30 unexposed people from the same industry.	Unspecified microwave frequencies, levels, exposure durations.	Both groups were examined independently by two eye specialists for visual acuity, opacities, and retinal lesions. No opacities were seen in those younger than 26 years in either group, but for each 5-year age span above 26 years, the percentages of opacities in the exposed group were higher than in the controls. Retinal lesions resembling scars after inflamatory reactions were seen in 19 of the 68 exposed persons versus only 1 of the 30 control persons.	The authors speculated that the higher incidence of retinal lesions in the exposed group may have been due to RFR-leakages from equipment or carelessness among that group.
Appleton and McCrossan (1972)	Initial ocular survey of 91 persons at Fort Monmouth, NJ, where various communication, detection, guidance, and weather equipment were being developed, tested, and used. The controls were 135 Post employees who had never worked with or were near microwave equipment.	Specific exposure data were not given, but all personnel with histories of working with lasers, microwave equipment, welding, xenon arcs, or ultraviolet were asked to participate.	The participating persons were given eye examinations without any foreknowledge of their histories. Only those with histories of working directly with microwaves were designated as the exposed group. Scored were the numbers and locations of opacities and vacuoles, and if posterior subcapsular iridescence (PSCI) was seen. Results were presented for the 10-year age spans 20-29 through 60-69. For corresponding experimental and control age subgroups, there were several higher percentages, several lower percentages, and several with no difference.	The lack of any statistical treatment of the data rendered it difficult to assess the findings for significance, and for possible linkage to RFR-exposure.

TABLE 14A: RFR AND OCULAR CHANGES

Authors	Effects Sought or Examined	Exposure Modality	Effects Reported	Notes & Comments
Appleton (1973)	Ocular survey extended by adding the data for personnel at 4 other Army bases, which yielded pooled totals of 605 exposed and 493 control personnel.	See Appleton and McCrossen (1972).	The findings for the larger data base were basically similar to those of the previous survey.	The author elaborated on the use of opacities, vacuoles, and posterior subcapsular iridescence (PSCI) as easily recognized diagnostic criteria of possible subclinical eye damage, and noted that one or more of these signs are seen more often in people as they age and in younger persons who are developing cataracts.
Appleton et al. (1975b)	Final results of the ocular survey at the 5 Army bases, which encompassed totals of 1542 exposed and 801 control subjects.	See Appleton and McCrossen (1972).	As in the earlier surveys, for each 10-year age span, some percentages for the exposed groups were higher than for the control groups and some were lower. The authors concluded that lens damage due to microwave radiation from military equipment had not occurred.	As before, the credibility of that conclusion is diminished by the lack of a statistical treatment of the data.
Shacklett et al. (1975)	Ocular surveys of 447 microwave personnel at 8 Air Force bases and of 340 age-matched controls.	Exposures based on histories of working around microwave-generating equipment.	High percentages of opacities, vacuoles, and posterior subcapsular iridescence (criteria the same as those used by Appleton and coworkers) were found in both the exposed and control groups, related primarily to aging and not associated with RFR-exposure.	Work histories, the microwave equipment types involved, and the times spent working around each type were obtained. Also studied were medical histories of the subjects and families, in a search for evidence of various ocular diseases.
Frey (1985)	This author took issue with the findings of Appleton and McCrossan (1972). He remarked that the exposure group likely included persons who were not RFR-exposed and the control group included RFR-exposed persons. He also criticized the lack of a statistical analysis.	See Appleton and McCrossen (1972).	Frey statistically analyzed the Appleton and McCrossan (1972) data, and indicated that the opacity incidences and the age differences were not related, from which he concluded that the exposed group as a whole had significantly more opacities than the whole control group. He compared the percentages of opacities in Appleton and McCrossen's control group with the percentages of cataracts in men published by the National Center for Health Statistics (NCHS), and concluded that the study was biased.	Not clear was why Frey (1985) chose to analyze the earlier Appleton and McCrossen (1972) study rather than the results of the larger Appleton et al. (1975b), which he dismissed as "also flawed". A similar comparison between the NCHS survey and the larger study shows that Frey's contention is specious.

TABLE 14B: RFR AND OCULAR CHANGES (CONTINUED)

Authors	Effects Sought or Examined	Exposure Modality	Effects Reported	Notes & Comments
Wike and Martin (1985)	These authors took issue with Frey's criticisms of Appleton and McCrossan (1972).	See Appleton and McCrossen (1972) and Frey (1985).	Wike and Martin's treatment of both the Appleton and McCrossen (1972) and the Appleton et al. (1975b) studies yielded the same conclusions: The occurrence of opacities was significantly associated with age and not with groups, rendering Frey's conclusion erroneous.	Wike and Martin remarked that Frey's comparison of opacity percentages with NCHS cataract percentages was inappropriate because the two endpoints are not identical. For various reasons, they also regarded Frey's statistical treatment as inappropriate.
Zaret (1974)	Cataract in a patient, with exposure to a microwave oven as the suspected cause.	Measurements of that oven yielded maximum leakage of 2 mW/cm^2 during operation and 40 mW/cm^2 on opening its door. The author estimated that the patient had used the oven for a total of about 850 hours and had opened its door about 8,500 times.	The patient's ophthalmologist reported finding extensive posterior subcapsular opacities and a few anterior subcapsular opacities and vacuoles in both lenses, which were more advanced in the right eye. Cataract extraction from the right eye was done subsequently.	Zaret (1974) indicated that microwave cataracts have a distinctive appearance. Appended to the paper were letters of comments, mostly critical of Zaret's findings, and a response by the author.
Hollows and Douglas (1984a)	Ocular effects in 53 radiolinemen exposed occupationally to RFR in Australia. The results of lens examination of the 53 subjects were compared with those for 39 non-radiolinemen matched in age from the same Australian states.	The RFR frequencies ranged from 558 kHz to 527 MHz, primarily from radio and TV towers. The power densities near work areas ranged from 0.08 to 4,000 mW/cm^2.	"Posterior subcapsular cataract" (PSC) was found in one or both eyes of 11 of the 53 radiolinemen (21%) versus in 3 of the 39 controls (8%), a nonsignificant difference ($p=0.086$). Alternatively, PSC was found in 19 of the 106 eyes (18%) of the radiolinemen versus in 6 of the 78 control eyes (8%), a barely significant difference ($p=0.043$).	The contribution of RFR to the difference in PSC incidence is not clear because nuclear sclerosis was seen in some of the radiolinemen.
Hocking (1984) & Harding (1984)	Disputed some aspects of the Hollows and Douglas (1984a) study.	See Hollows and Douglas (1984a)	Hollows and Douglas (1984b) responded with explanations about how the subjects were selected, and that the frequencies and power-density measurements had been provided by Dr. Hocking's organization.	At issue were how the 53 subjects were selected from 223 linesmen (comprising only 23%) and the accuracy of the exposure levels.

TABLE 14C: RFR AND OCULAR CHANGES (CONTINUED)

Authors	Effects Sought or Examined	Exposure Modality	Effects Reported	Notes & Comments
Hocking et al. (1988)	Effects of exposure of 9 radio linemen to an open waveguide that had been inadvertently activated. All 9 men were given medical examinations, their eyes were examined periodically for 9 months, and samples of blood and semen were evaluated.	Two of the 9 men had been exposed to 4.1-GHz RFR at 4.6 mW/cm^2 for up to 90 minutes (the "high-exposure" group). The range of SARs in their lenses was calculated to be 1.2-1.5 W/kg. The other 7 (the "low-exposure" group) were exposed at less than 0.15 mW/cm^2.	Various eye abnormalities were found in both groups in the first post-exposure ophthalmic examination, but vision was normal in all of the men. In the second examination, eye changes were found in both groups, but the third examination showed no further changes. One man of each group had a significant rise in creatine phosphokinase. Those in the high-exposure group showed no other significant biochemical or hematologic abnormalities. Three of the low-exposure men showed mild abnormalities in liver function, ascribed to alcohol consumption.	The authors concluded that the slight abnormalities observed in both the high-exposure and low-exposure groups were inconsistent and unlikely due to the RFR-exposure.

TABLE 14D: RFR AND OCULAR CHANGES (CONCLUDED)

2.4.2 CONCLUSION

The epidemiologic ocular studies by Cleary et al. (1965), Cleary and Pasternack (1966), Appleton and coworkers (1972, 1973, and 1975b), Shacklett et al. (1975), and Hocking et al. (1988) did show age-related ocular changes but no credible evidence of ocular damage due to chronic RFR-exposure. Frey (1985) took issue with the negative findings of Appleton and McCrossen (1972), but Wike and Martin (1985) responded with a treatment of the data in both Appleton and McCrossen (1972) and Appleton et al. (1975b), which showed that opacity occurrence was associated with age rather than RFR; Frey (1985) had ignored the larger Appleton et al. (1975b) study that included the Appleton and McCrossen (1972) results.

Aurell and Tengroth (1973) reported higher incidences in ocular damage in personnel testing klystrons and measuring microwave radiation than in controls or in laboratory personnel, but the numbers of people in each 5-year age group studied were too small to ascribe credence to the findings. Also, no controls older than 41 years were included, rendering it impossible to separate lens opacities due to RFR-exposure from senile cataracts. Hollows and Douglas (1984) found a barely significant excess of "posterior subcapsular cataracts" in radiolinemen, but the RFR contribution was unclear because nuclear sclerosis was also found. See also the comments by Hocking (1984) and Harding (1984) regarding the selection of the subjects and the accuracy of the RFR levels in the Hollows and Douglas (1984a) study, and the response thereto by Hollows and Douglas (1984b).

Taken collectively, the epidemiologic studies of ocular damage yielded no evidence that chronic exposure to low levels of RFR (i.e., below prior and current exposure guidelines or thresholds determined from animal studies) would cause damage to human eyes.

The occurrence of cataracts in a patient, asscribed by Zaret (1974) to leakage of RFR from a "faulty" microwave oven were disputed in comments by other investigators. Zaret has characterized microwave cataracts as different from cataracts due to other causes, a distinction that is not recognized by other ophthalmologists.

2.5 RFR AND CANCER INCIDENCE

Lester and Moore (1982a) postulated that prolonged, repeated exposure to weak RFR might be associated with increased cancer incidence. Because radars have been in operation at military air bases since World War II, the authors hypothesized that detectable increases in cancer mortality might be found in areas surrounding air bases. To test this hypothesis, they searched "Guide to Air Force Bases" (Air Force Magazine, 1969) to locate Air Force Bases (AFBs) in the continental United States that were operational in the period 1950-1969, and found 92 counties that had at least one AFB. They then ascertained the population in each of those counties from 1960-census data (CENSUS, 1967), and selected a control county for each AFB county, defined as the one in the same state that was closest in population (either larger or smaller) that did not have an AFB. For the AFB counties, the mean population and the SD were 237,684 and 254,683, respectively; the corresponding values for the non-AFB counties were 209,893 and 242,128. The difference between those distributions was not statistically significant.

The authors indicated that data on civilian air bases for that period were not available. They also stated: "It should be noted that many counties in both groups had other air bases. Also, the counties varied considerably in geographic and economic characteristics. These factors would tend to bias the data against the hypothesis. Despite this confounding, the design demands that the presence of an AFB produce sufficient electromagnetic effect that it would be relatable to a higher cancer mortality in that county. No attempt was made to assess the possible role of other carcinogens."

Cancer mortality ratings (deaths from all types of cancer) for AFB and control counties were obtained from the "Atlas of Cancer Mortality for U.S. Counties: 1950-1969" (HEW, 1975). The authors age-adjusted those mortality data and indexed them in the following five categories with respect to cancer mortality in the general U.S. population:

MORTALITY RANKING	LESTER AND MOORE INDEX
Significantly high, in highest decile	4
Significantly high, not in highest decile	3
In highest decile, not significant	2
Not significantly different from U.S.	1
Significantly lower than U.S.	0

Data were available separately for males (M) and females (F). Lester and Moore (1982a) presented the results shown in Table 15 (their Table 1):

TABLE 15: LESTER AND MOORE (1982a) CATEGORIES OF CANCER MORTALITY

	MALES		FEMALES		INDEX
	Counties		Counties		
	AFB	nonAFB	AFB	nonAFB	
	21	12	13	7	4
	2	1	4	2	3
	5	6	0	3	2
	16	21	33	34	1
	48	52	42	46	0
Totals:	92	92	92	92	

From those results, the authors made the following assumptions:

a. Categories 4 and 3 can be combined as significant incidence (+); categories 1 and 0 as nonsignificant incidence (-).

b. Category 2 can be deleted.

c. Since there was an effort to match counties by population, the proper statistical analysis is a test for correlated proportions comparing AFB with nonAFB counties.

The authors then reclassified their data in pairs as shown in Table 16 (their Table 2):

TABLE 16: RECLASSIFIED LESTER AND MOORE (1982a) CANCER MORTALITY DATA

INCIDENCE	M	F
AFB (+) and nonAFB (+)	9	7
AFB (-) and nonAFB (-)	57	70
AFB (+) and nonAFB (-)	12	10
AFB (-) and nonAFB (+)	4	2
Totals	82	89

Their "test for correlated proportions, corrected for continuity, one-tailed test" of the data in Table 16 yielded p=0.04 for males, p=0.02 for females, from which they concluded that AFB counties, when compared with population-matched nonAFB counties, had a significantly higher incidence of cancer mortality for the period 1950-1969.

This paper is one of only a few in the scientific literature to suggest that exposure to RFR is linked with increased cancer incidence and mortality. However, their results as presented do not confirm that increased cancer mortality is associated with RFR-exposure, but only that such mortality appears to be correlated with the presence of an operational AFB.

The test for a statistically significant difference between the AFB and control counties depends heavily on how well the control counties were matched with the AFB counties in all factors except the presence of an AFB. The AFB identities were not given in the paper, so on inquiry, Dr. J. Lester kindly made available the raw data. A review of those data revealed several apparent inconsistencies, so an independent analysis was conducted using the list of AFBs provided by Dr. Lester and the methodology described in the paper.

For the independent analysis, the Rand McNally "1982 Commercial Atlas and Marketing Guide" (Rand McNally, 1982) was used to ascertain the counties in which the specific AFBs were located. The populations of those counties were determined from CENSUS (1967), the reference used by Lester and Moore, and the control counties closest in population in the same state were identified. The categories of male and female cancer mortality for the control and AFB counties were obtained from HEW (1975), also used by Lester and Moore. On reassembly of the raw data, the following emerged:

1. The total number of AFB counties was reduced to 91 because one county was counted twice (Luke AFB and Williams AFB are in the same county).

2. Of those 91, Lester and Moore located 13 AFBs in incorrect counties.

3. In 43 of the remaining 78 cases, Lester and Moore either used the incorrect control county (as defined above) or incorrectly assigned the M or F category to the control county.

4. Of the remaining 35 cases where Lester and Moore had selected the AFB and control counties correctly, there were 22 cases (16 counties) for which they had incorrectly assigned the M or F categories.

Thus, of the original 92 AFB/control county pairs of data used by Lester and Moore, only 19 and their M and F categories appeared to be correct. Use of the corrected data for the 91 AFB counties yielded Table 17:

TABLE 17: REVISION OF TABLE 15

	MALES		FEMALES		INDEX
	Counties		Counties		
	AFB	nonAFB	AFB	nonAFB	
	16	10	9	7	4
	0	1	3	3	3
	6	8	0	2	2
	17	24	33	36	1
	52	48	46	43	0
Totals	91	91	91	91	

Reclassification of these data based on the assumptions of Lester and Moore yielded Table 18:

TABLE 18: REVISION OF TABLE 16

INCIDENCE	M	F
AFB (+) and nonAFB (+)	6	6
AFB (-) and nonAFB (-)	58	73
AFB (+) and nonAFB (-)	10	6
AFB (-) and nonAFB (+)	6	5
Totals	80	90

A statistician was consulted about the "test for correlated proportions" used by Lester and Moore. A test by this name does not appear in any of the references familiar to the statistician. However, McNemar's Test (Fleiss, 1981) is suitable and is similar to the test by Lester and Moore because use of this test yielded the same z and p values cited by Lester and Moore for Table 16 (their Table 2). McNemar's Test of the data in Table 17 yielded z=0.7, p=0.23 for males and z=0, p=0.50 for females, both nonsignificant.

In summary, an independent reanalysis of data for 91 AFB counties found by Lester and Moore (1982a) and the population-matched control counties not having an AFB did not confirm their finding. Instead, counties with an AFB had incidences of cancer mortality for either males or females, for the period 1950-1969, that did not significantly differ statistically from those in counties without an AFB that were most closely matched in population. The original finding of significance by Lester and Moore (1982a) apparently was the result of an incorrectly assembled data base. This reevaluation was published by Polson and Merritt (1985) in the same journal, together with a response by Lester (1985), who took issue with some aspects of the reanalysis and did not accept the revised finding.

In another study, Lester and Moore (1982b) sought to determine whether there was a geographic pattern of cancer incidence within the city of Wichita, Kansas, and whether specific sources of RFR could be identified and related to any such pattern. The authors reported finding a neighborhood pattern of cancer incidence in that city, with the suggestion of a time element in its appearance, and noted that cancer tended to occur on leading terrain crests

relative to radar transmissions and was less frequent in the valleys. They presented a formula relating cancer incidence to the terrain and the presence of RFR, which led to their overall finding that cancer incidence in Wichita appears to be related to the probability of exposure to radar.

At that time, Wichita had a population of 262,766 (from a 1973 census). With the exception of two industrial areas, it was divided into 94 census tracts of approximately equal population. However, Lester and Moore (1982b) included only 76 of the tracts in their analysis. The Department of Community Health had stratified the tracts into three health and economic classes (good, fair, poor), based on determinants such as levels of education, income, crowding, unskilled workers, infant mortality, venereal disease, tuberculosis, and housing. Regarding freedom from air pollution, Wichita then ranked second out of 52 major cities of over 80,000 population in the United States, thus presumably removing that agent as a possible confounding factor.

The city lies on essentially a flat plain bisected by the Arkansas River, with two low ridges (100-ft and 20-ft elevation changes) to the west and northwest of the city limits. Wichita Mid-Continent Airport lies 9.7 km southwest and 35 ft higher than the city center. McConnell AFB is located 7.2 km southeast and 130 ft higher than the city center.

The authors obtained morbidity data on all first diagnosed cancer cases of Wichita residents for 1975, 1976, and 1977 from five city hospitals, for a total of 3004 cases for the three years. The ratio of the number of diagnosed cases to the tract population for each year yielded the incidence rates for the 76 census tracts considered. They then analyzed the data on the incidence rates, age, economic stratification (of the residence tract of each person), male/female ratio, and race, and obtained a correlation matrix for those 76 tracts. They also obtained mortality data for all cancer deaths of Wichita residents for 1975, 1976, and 1977, and analyzed the incidence rates, age, economic stratification, male/female ratio, and race, thereby obtaining a correlation matrix for the 76 census tracts.

The formula derived by the authors for treating the data was based on the following hypotheses: First, the major contributors to RFR-exposure were the radar transmitters at the airports. Second, radar exposure is by line-of-sight. Third, RFR-exposure correlates directly with elevation. Fourth, any shielding by intervening terrain confounds the elevation exposure criterion.

This paper is replete with flaws, the most serious of which is that the authors, "to find a possible connection between cancer incidence and external electromagnetic fields," assumed that the population is exposed only to the RFR from radars at the two airports adjacent to the city. They provided no measurements to support this assumption and gave no indication that the scan sectors of such radars were considered. It is noteworthy, however, that the Environmental Protection Agency (EPA) had measured ambient RFR levels in 15 major cities around the United States (Tell and Mantiply, 1980), which showed that by far the major contributors to environmental levels of RFR are FM and TV broadcast transmitters, not radar systems (Janes, 1979). Although the EPA did not include Wichita among the cities it surveyed, it would be reasonable to assume that the RFR environmental situation there differed little from those of the 15 cities surveyed.

Even if the assumption above that the radars were the primary exposure sources were taken as correct, a model of RFR-exposure should have been used that is based on the physical laws of RFR propagation, particularly the inverse-square-law of attenuation with distance, and the RFR shielding effects of artificial structures and buildings as well as of the terrain. Other flaws in the paper were the arbitrary assumptions for the heights of the radars and the false precision imparted by citing the city and airport elevations to five significant figures ("average" elevations accurate to within 5 mm).

Unfortunately, the propagation and exposure model used by the authors bore no relationship to such factors, and any conclusions drawn therefrom are unrelated to the actual exposure levels. Instead, the results of this paper appear to be a good example of spurious correlation. Any relationship between radar exposure and cancer incidence, if such existed, was not demonstrated by the data and analysis presented in this paper.

In a correspondence item, Milham (1982) presented data showing higher than expected mortality rates from "all leukemia" and from "acute leukemia" in men in occupations that presumably involved exposure to electric and magnetic fields. The author ascertained the expected numbers of deaths from 158 causes (including various forms of leukemia) in white males of age 20 years and older who resided in Washington State during 1970 through 1979, standardized by age and year of death. He then determined the number of deaths from each cause in each of 218 coded occupations and calculated the ratio of the number of deaths from each cause in each occupation to the expected number of deaths from that cause, the "proportionate mortality ratio [or rate]" (PMR), usually expressed as a percentage. A total of 438,000 deaths were thus analyzed.

Statistical treatment of the data was not given, but the PMRs for seven of the 11 occupations assumed to have involved exposure to electric and/or magnetic fields were marked as not statistically significant. However, for the four remaining occupations (electricians, television and radio repairmen, power-station operators, and aluminum workers), the PMRs for all leukemia were 138, 157, 259, and 189, of which three were indicated as significant at the $p<0.01$ level; the exception was for the television and radio repairmen, for which there were only 5 cases versus 3.2 expected, numbers too small to render their ratio statistically significant. The PMRs for acute leukemia in the same four occupations were 178, 291, 282, and 258. Again three of the PMRs were marked $p<0.01$, but the nonsignificant exception was for power-station operators. The author surmised that the significant increases in mortality from leukemia were associated primarily with exposures to large dc electric currents and high alternating electric and magnetic power fields.

Reported in this correspondence item was one aspect of a much larger study by Milham (1983), which is discussed in detail below. As indicated therein, the findings of this aspect are questionable for the use of the PMR, because PMRs for the causes of death considered are generally interdependent. Thus, a significantly high PMR for one cause may indicate a real increase in deaths from that cause, but also may be ascribable instead to an unexpected but real low PMR for one or more of the other causes considered.

Liburdy (1982) took issue with the finding of Milham (1982), citing several references that do not support it, including Dwyer and Leeper (1978), a NIOSH report on carcinogenesis and nonionizing radiation. Liburdy noted:

"The report cites over 60 quantitative studies that identify mutagenic, teratogenic, developmental, hematologic, and neurologic effects. Although these phenomena are implicated in the process of carcinogenesis, cancer was not observed...Negative results do not conclusively rule out a health risk; the data, however, argue against an association."

Wright et al. (1982), using data on proportional incidence ratios (PIRs) for male cases in the Cancer Surveillance Program of Los Angeles County during the years 1972 to 1979, indicated that there is a trend toward higher risk of leukemia from occupational exposure to electric and magnetic fields, with the greatest risk for acute myelogenous leukemia (AML). However, they stated: "The occupations grouped as sharing exposure to electric and magnetic fields indoubtedly share other exposures. While significant exposure to ionising radiation is probably not present in most of these jobs, metal fumes, solvents (including benzene), fluxes, chlorinated biphenyls, synthetic waxes, epoxy resins, and chlorinated naphthalenes are other exposures that may be shared."

McDowall (1983) presented PMRs for occupational mortality in England and Wales during 1970 to 1972 in males 15-72 years of age, indicating that the distribution of mortality for all leukemias did not differ significantly from expected. Noteworthy with respect to RFR-exposure (as defined herein) is that the PMRs ranged from a low of 61 for radio and radar mechanics to a high of 249 for telegraph radio operators. However, the PMRs specific for AML were 231, 241, 213, and 305 respectively for electrical engineers (self-described), telegraph radio operators, professional electrical engineers, and professional electronic engineers, values significantly above 100.

Those authors also did a case-control study of death of 537 males from AML in the year 1973, with 1074 male decedents from all causes except leukemia selected as controls. The results were significantly elevated relative risks (RRs) for electrical occupations, with the highest RR for telecommunications engineers.

Coleman et al. (1983), noting the studies by Milham (1982), Wright et al. (1982), and McDowall (1983), reported on a study of leukemia incidence among men in 10 electrical occupations in South-East England. The authors noted that the South Thames Cancer Registry listed about 30,000 tumors a year in a population of 6.5 million, and calculated the proportional registration ratio (PRR) for leukemia in males of ages 15-74 years during 1961-1979. They compared the number of registered leukemias in males of each five-year-age group in each of 10 electrical occupations with the number expected if the proportion of leukemias were the same as for the men in all occupations. Their null hypothesis was that the proportion of men with leukemia in each electrical occupation would be the same as the proportion of men with leukemia in all occupations.

Their analysis indicated a 17% excess of all leukemias in all electrical occupations (seen in 113 of 117 cases versus 96.5 expected; PRR=117, 1-sided $p<0.05$). However, although 8 of the 10 occupations showed excesses (PRRs exceeding 100), the occupation "radio/radar mechanics" showed a deficit for all leukemias (1 in 22 cases versus 4.63 expected; PRR=22, $p=0.07$). The PRRs for all electrical occupations also indicated no overall excess of chronic myeloid leukemia, but a 46% excess of acute lymphoid leukemia, a 29% excess of chronic lymphoid leukemia, and a 23% excess of acute myeloid leukemia. The

excesses of acute myeloid leukemia, consonant with the findings of the other studies cited, were in seven of the occupations, but not all were significant statistically, and there were no cases in occupations "radio/radar mechanics" or "professional electronic engineers".

In the detailed report mentioned above, Milham (1983) analyzed the information on age and year of death in Washington State of 429,926 male decedents for 1950-1979 and 25,066 female decedents for 1974-1979, and presented cause-of-death analyses (160 causes) for 219 male and 51 female occupational categories. The author stated:

"The Washington State mortality pattern is, in general, consistent with both the Registrar General's results and with the published literature. Some of the new occupational mortality findings published in the 1950-1971 report and in this updated version have been confirmed. Others warrant follow-up. These include a lung cancer excess in workers at the ASARCO Tacoma copper smelter, increased mortality due to multiple myeloma and pancreatic cancer in workers at the Hanford atomic energy facility, and excess mortality due to cancer of the pancreas, lymphoma, leukemia, and emphysema in aluminum workers.

"New findings in this report are a leukemia increase in workers exposed to electric and magnetic fields and a deficit of multiple sclerosis deaths among outdoor workers."

In this report, 20 microfiche negatives were provided in addition to 167 pages of text; these microfiches contained the detailed raw mortality data and the calculated proportional mortality ratios (PMRs) for males and females by gender occupations. (The occupation of each decedent was obtained from the statement on the Washington-State death certificate.) Also contained in the microfiches was additional information on occupations ranked by PMR within each cause of death, and causes of death with significantly ($p<0.05$) elevated or reduced PMRs by occupation, both for the males only. Eighty pages of the printed report described the occupation codes (common for both men and women) used in filling out the death certificates, the occupation groupings for men, the occupation groupings for women, an index of occupations for men, and an index of occupations for women.

Milham's (1983) analysis progressed from the raw mortality data through successive clusterings of the data in like occupational groupings, presumably to obtain sufficient numbers in each cluster to permit meaningful statistical analysis. As noted in Milham (1982), the proportionate mortality ratio (PMR) was used. Epidemiologists Lilienfeld and Lilienfeld (1980) have stated (pp. 74-75): "The proportionate mortality rate does not directly measure the risk or probability of a person in a population dying from a specific disease as does a cause-specific mortality rate." Moreover, the method used by the aforementioned Registrar General is the more common "standardized mortality ratio" (SMR), because it represents the percentage of actual deaths for each cause relative to the expected number of deaths from that cause, independent of any other SMR, as described on pages 78-80 in Lilienfeld and Lilienfeld (1980).

Milham's printed report contained 63 pages of one-paragraph commentaries that described the mortality pattern in each of the occupation groupings as seen by the author. There were 219 such commentaries for males and 51 for

females. Some of these commentaries appear to be highly subjective and to reflect the personal biases of the author. For example, the commentary below on female mortality in one occupation was given on page 63:

"Waitresses
Occupation code 875
Total deaths 862

"Cancers of the esophagus, stomach, larynx, lung, cervix and uterus unspecified have increased PMRs. Psychoses, pulmonary emphysema, cirrhosis of the liver, motor vehicle accidents, and homicide have mortality increases. Much of this mortality pattern may be due to life-style patterns, i.e., smoking, drinking, and promiscuity."

Other commentaries seem to include some nonsignificant but elevated PMRs because the author apparently believed that they contribute to the over-all mortality pattern considered appropriate by him for that occupation. For example, page 54 has the following commentary:

"Dietitians and Nutritionists
Occupation code 073
Total deaths 104

"These women show a significant excess of malignant neoplasms of the digestive organs (PMR=254 based on 7 deaths) in the 20-64 age class. This is due to 4 deaths observed due to cancer of the pancreas to less than 2 expected. Malignant neoplasms of lymphatic and hematopoietic tissues (age 20-64) show a PMR of 476 based on 5 deaths, 3 of which were in the other lymphoma category. Diabetes mellitus had a PMR of 225 based on 5 deaths."

It is seen that of 104 total deaths in this occupation for women, the author had selected 17 deaths and presented them as though dietitians and nutritionists might be expected to die more often of malignant neoplasms of the digestive organs and diabetes mellitus. The other 87 deaths were ignored. This clearly demonstrates a subjective and selective bias in the author's application of the PMR analytical technique.

The author carried the analysis one step further by examining mortality by cause of death and by showing occupational groupings with statistically significant elevations or reductions in PMR. There are several problems with some of the patterns that emerged in this treatment. On page 67, for example, in the commentary on male mortality by occupation within cause-of-death groups is the following:

"Malignant Melanoma of Skin (ICD 190)

"Three of the four occupations with high PMRs (clergymen, school teachers, hotel managers) have no obvious relationship to outdoor work or exposure to sunlight. Navy and Coast Guard personnel, however, probably are exposed to sunlight."

This presumption that Navy and Coast Guard personnel have elevated PMRs for malignant melanoma of the skin because they are exposed to sunlight would seem to indicate a considerable bias on the part of the author. He did not indicate why these personnel would spend more time in the sun than school teachers, for instance, other than his personal belief that they do so.

In the next step in the analysis, Milham examined the mortality patterns of groups of selected occupations that appeared to have similar environmental exposures. It is here, on one page (75) of the entire report, that categories of workers presumed to be occupationally exposed to magnetic and/or electrical fields are juxtaposed and PMRs for two categories of leukemia (acute leukemia, and all leukemia) are presented. Shown were the following 11 occupations: electrical engineers, electronic technicians, radio and telegraph operators, electricians, power and telephone linesmen, television and radio repairmen, motion picture projectionists, aluminum workers, streetcar and subway motormen, power station operators, and welders and flame cutters.

Of the 22 categories for the two leukemia categories by 11 occupations, there were 3 cases where the PMR was significant at the 1% level, plus 2 at the 5% level. The other PMRs, though elevated in 13 cases and depressed in 3 (with 1 the same), were not statistically significant. The significant cases, electricians (both categories of leukemia), aluminum workers (both categories of leukemia), and power station operators (all leukemia only), comprised 79 of the total of 136 leukemia deaths actually observed in those occupations. The excess number of deaths (observed minus expected) for those three occupations was 28. On page 5, the author stated the following on the PMR technique:

"The major flaw of the proportionate mortality ratio (PMR) is that it says nothing about total force of mortality for a given occupation... All occupations have a total PMR of 100. Also, since the cause-of-death specific PMRs must sum to 100, a very high or low PMR in a common cause-of-death group will affect the other PMRs for that occupation."

In other words, by virtue of the technique itself, the 5 significantly high PMRs mentioned above might have arisen because other PMRs in three of the 11 occupations were abnormally low. In view of this point, little credence can be given to the author's claim that the increased PMRs for all leukemia and for acute leukemia are associated with exposure to electric and magnetic fields. The other point to be made is that there must be a dose-response relationship to conclude that cause-and-effect applies in this or in other epidemiologic studies. At best, such a relationship is unproven here; without exposure data for the individuals or even for the occupations, it is solely an assumption that persons in these occupations actually do experience greater exposure to electrical and magnetic fields than do those in other occupations. For example, electricians, the occupation with the largest number of leukemia deaths (51), actually spend a large part of their time working on circuits that are not energized.

Perhaps the strongest criticism of this study as a whole is that it illustrates an approach that statisticians commonly refer to as "data mining," in which a very large data base is "picked over" for "nuggets" of (locally) statistically significant items, which are then assembled to show purported relationships. The usual statistical methodology is reversed: statistical significance is found first and then hypotheses are formulated. However, epidemiologists do recognize and characterize such studies as appropriate for "hypothesis generation," but give little credence to any specific quantitative findings therefrom; instead, they give more credence to specific studies in which hypotheses, however derived, are tested *a priori*.

In summary, when examined in the context of the complete report of occupational mortality in Washington State, the claim that workers who had been exposed occupationally to electric and magnetic fields showed increased incidence of all leukemia and acute leukemia is seen to be weak at best. The methodological approach used did not meet usual criteria for the statistical testing of hypotheses: no hypotheses were assumed *a priori*. The commentaries on the patterns of mortality underlying the different occupations from which the groups were selected, such as electric and magnetic field workers, seemed to show personal bias by the author, and use of the PMR technique could have yielded an apparent increase in the PMR in one cause-of-death category from an abnormally low PMR in another category. Therefore, the purported relationship between leukemia and exposure to electric and magnetic fields found by Milham (1983) is questionable. (These criticisms apply equally to the cause-and-effect relationships claimed in the report for other agents and occupations.)

In a brief report, Milham (1985) described his study of mortality in male members of the American Radio Relay League (ARRL), a group of amateur radio operators presumably exposed to RFR while operating their transmitters. For the years 1971-1983, 296 deaths of male members in Washington State and 1642 in California were listed in QST, the monthly ARRL publication. Death certificates were obtained for 280 (95%) of the Washington decedents, and information on the age, date, and cause of death was obtained for 1411 (86%) of the California decedents, a total of 1691 deaths. A proportional mortality ratio (PMR) of 281 was found for acute, chronic, and unspecified myelogenous leukemia (16 deaths found versus 5.7 deaths expected, $p<0.01$); the PMR for monocytotic leukemia was only 77 (well below 100), and was 0 for lymphatic leukemia. Thus, the PMR for all leukemias was 191 (24 deaths versus 12.6 deaths expected, $p<0.01$). The author noted that many of the ARRL members are employed in occupations involving exposure to electromagnetic fields, but that occupational exposure alone does not explain the excess deaths.

Wangler et al. (1985) disagreed with Milham's (1985) suggestion that there may be a greater than normal leukemia risk in amateur radio operators, based on several points. First, they questioned the selection of radio amateurs to test that hypothesis, citing a 1980 survey in Canada and the U.S. that showed that typical amateurs spent 6.1 hours per week on that activity, much of which was highly variable and most of which involved listening, with intermittent transmissions at low average radiated powers. Second, they cited Milham's statement that 35% of the amateurs in Washington State had been employed in electrically related occupations, and queried how many of the higher leukemia deaths were occupationally related. Third, they noted that the "silent keys" are not representative of the amateur radio community as a whole because they are listed in QST only when reported by a family member. Fourth, they noted the possibility of exposures of the decedents to toxic chemicals. Last, they questioned the statistical treatment used.

Coleman (1985) took issue with the comments by Wangler et al. (1985) regarding Milham's (1985) statistical methodology and conclusions, except for the point about the use of the "silent keys".

In a subsequent study, Milham (1988a) examined the mortality data for a larger number of amateur radio operators. He extracted the names of 67,829 males in Washington State and California listed as licensed in the 1984 U.S. Federal Communications Commission Amateur Radio Station and/or Operator File

between 1 January 1979 and 16 June 1984. Those names were searched for deaths during the five-year period from 1 January 1979 to 31 December 1984, which yielded a total of 2,485 male decedents taken to have had 232,499 person-years at risk. Herein, the author used the standardized mortality ratio (SMR). For an SMR exceeding 100, whether the excess number of deaths is statistically significant depends on the size of the 95% confidence interval for that SMR, and similarly for a smaller than expected number of deaths that yields an SMR less than 100.

The total number of expected deaths in both states from all causes was 3,479, so the 2,485 deaths of licensees yielded an SMR of 71, with a 95% confidence interval of 69-74, indicating significantly lower death rates for licensees than in the general population. The largest number of deaths, 1208, were in the category "all circulatory diseases". However, 1732 deaths were expected, so that the SMR was only 70 (95% confidence interval: 66-74), also indicating a significantly lower death rate than in the general population.

In the category "all malignant neoplasms," there were 741 deaths versus 839 expected, yielding an SMR of 89 (95% confidence interval: 82-95), again a significantly lower death rate than for the general population. The only subcategory of malignant neoplasms that yielded an SMR significantly exceeding 100 was "other lymphatic tissue," in which there were 43 deaths versus 27 expected. The SMR was 162, with a 95% confidence interval of 117-218. The subcategory "leukemia" had 36 deaths versus 29 expected, for an SMR of 124, but the 95% confidence interval was 87-172, thus rendering this finding nonsignificant. The author considered nine subdivisions or sub-subdivisions of "leukemia" and found that of the 36 deaths, 15 were for "acute myeloid leukemia" versus 8.5 of the expected 29. These values yielded an SMR of 176 with a 95% confidence interval of 103-285, a statistically significant result. However, little if any credence can be given to this finding, in view of the small numbers of deaths relative to the actual and expected totals. Thus, despite any claims to the contrary by the author, the results of this study do not offer any confirmation of those in Milham (1983).

In another brief paper, Milham (1988b) also presented an analysis of the mortality data for amateur radio operators in Washington State and California by five Federal-Communications-Commission license classes: novice, technician, general, advanced, and extra. The novice class covered the usual entry-level or beginners license, and the other four classes included the operators with successively increasing technical knowledge and skill (Morse-code speed). The mean ages of the licensees in each class were 38.4, 44.3, 49.5, 51.4, and 49.2 years, respectively, with an overall mean of 46.8 years.

Table 19 (adapted from Table 1 of the paper) shows the numbers of deaths and SMRs in each class from all causes, all malignant neoplasms, and various specific types of malignancies. The author did not provide the 95% confidence intervals, but did mark the significant ($p<0.05$) SMRs.

Cause of Death	Novice (n=12,279)		Technician (n=13,702)		General (n=18,649)		Advanced (n=17,436)		Extra (n=5,763)		All (n=67,829)	
	Deaths	SMR	Deaths	SMR	Deaths	SMR	Deaths	SMR	Deaths	SMR	Deaths	SMR
All causes	247	61*	409	80*	862	81*	798	69*	169	49*	2,485	71*
All malignant neoplasms	78	81	117	94	236	92	253	90	57	73	741	89*
Brain cancer	1	34	4	112	11	175	11	174	2	114	29	139
Lymphatic and hematopoietic neoplasms	9	101	18	163*	26	119	27	115	9	134	89	123*
All leukemias	5	139	7	160	10	114	10	105	4	145	36	124
Myeloid leukemia	1	43	6	230	5	141	5	151	1	91	18	140
Multiple myeloma and other lymphomas	3	96	8	199	15	184*	13	147	4	161	43	162*

*p<0.05

TABLE 19: MORTALITY IN AMATEUR RADIO OPERATORS BY FCC LICENSE CLASS

[Milham (1988b)]

Table 19 indicates that the SMRs for all causes of death were all significantly less than 100. Also, for deaths from all malignant neoplasms, the SMRs for all five license classes were below 100 and nonsignificant, but the collective SMR for that category was 89 and marked significant. As in Milham (1988a), both results may indicate that amateur radio operators are healthier than the general population.

On the other hand, the SMRs for lymphatic and hematopoietic neoplasms all exceeded 100, but the only significant excess was for the technician-license class, a result that rendered significant the collective SMR for that death category. Similarly, except for the novice class, the SMRs for multiple myeloma and other lymphomas exceeded 100, but the excess was significant only for the general-license class, again rendering the collective SMR for that death category significant. In both cases, however, the numbers of deaths were small: 18 of 409 deaths in the technician-license class and 15 of 862 deaths in the general-license class. Thus, as for the previous studies by this author, the findings above and the author's interpretation thereof are open to question.

Pearce et al. (1985), citing their then unpublished case-control study of possible relationships between leukemia incidence and various agricultural occupations in New Zealand, reported leukemia excesses in specific occupations "with potential for exposure to electrical and magnetic fields associated with alternating current". That study was of 546 male leukemia patients registered during 1979-1983 at ages 20 years and older, and the controls were 2,184 males chosen from the New Zealand Cancer Registry, with 4 controls per case matched on age and registration year.

In this brief paper, the authors extracted and tabulated the leukemia odds ratios (ORs) and 95% confidence limits (CIs) for those in the following specific occupations: electrical and electronic engineers, electrical and electronic technicians, electrical fitters, electronic equipment assemblers, radio/television repair, telephone installers, linemen, and power-station operators for a total of 18 of the 546 leukemia cases. The controls totaled 43 persons. Statistically significant leukemia excesses were shown for the electronic equipment assemblers (4 cases versus 0.5 expected, for an OR of 8.17, a CI of 1.49-44.74, two-tailed p=0.02), and in the radio/television repair category (7 cases versus 1.5 expected, OR=4.75, CI: 1.59-14.23, two-tailed p=0.01). [As noted below, the occupations for these two results were stated erroneously in the table.] There was also a nonsignificant excess in the power-station operators (1 case versus 0.3 expected, OR=3.93, CI: 0.25-63.08, p=0.33). Two hypotheses were suggested for the excesses: (1) exposure to nonionizing radiation, and (2) exposure to metal fumes and other substances used in electrical components or their assembly.

Pearce (1988) noted that the excesses above should have been ascribed to the occupations radio/television repair and electricians, respectively, and that there were no cases in the electronic equipment assemblers category. The correct results are shown in Table 20 (adapted from both papers). The authors noted that some of the additions are approximate because of rounding.

TABLE 20: ODDS RATIOS FOR LEUKEMIA IN SPECIFIC OCCUPATIONS
[Pearce (1988)]

Type of Electrical Work	Exposed Cases	Expected Cases	Controls	Odds ratio (95% CI)	2-tailed p value
Electrical/electronic engineers	1	1.3	5	0.79 (0.09-6.79)	0.83
Electrical/electronic technicians	1	1.0	4	1.04 (0.12-9.37)	0.97
Electrical fitters	2	3.0	12	0.67 (0.15-3.02)	0.61
Electronic equipment assemblers	0	---	0	-------	----
Radio/television repair	4	0.5	2	8.17 (1.49-44.74	0.02
Electricians	7	1.5	6	4.75 (1.59-14.23)	0.01
Telephone installers	0	0.3	1	-------	0.74
Linemen	2	3.0	12	0.66 (0.15-2.96)	0.59
Power-station operators	1	0.3	1	3.93 (0.25-63.08)	0.33
Totals:	18	10.8	43	1.70 (0.97-2.97)	0.06

As seen above, significant excesses were reported for radio/television repair and electricians, which, along with citations to the findings of Milham and others, led the authors to give greater credence to hypothesis (1) above. However, the findings are questionable from a statistical viewpoint, primarily because of the small numbers of cases. Moreover, without any valid rationale, the authors ignored the nonsignificant excesses (and decreases) in leukemia cases in the other occupations they designated as "electrical" (and therefore possibly subjected to exposure to electric and magnetic fields), which yielded an overall OR that was nonsignificant. Another point was their unjustifiable display of the ORs and CIs to three or four significant figures, conveying an impression of higher accuracy for the findings than is warranted.

Pearce et al. (1989) described a more extensive case-control study of electrical workers in New Zealand. The study involved 19,904 male patients with all types of cancer registered during 1980-1984 at ages 20 years and older at time of registration and whose occupations were recorded (about 80% of the total number of cases). The analysis was focused on those with the electrical occupations previously considered, and some patients previously considered were included in the present study. The control group for those with cancer at any specific site (or cancer type) consisted of those with cancer at other sites.

There were 488 cancer cases in those electrical occupations. Of the 22 sites or cancer types tabulated, half had ORs less than 1.0 and the other 11 had ORs in the range 1.0 to 1.62. However, all of those 11 sites had CIs that spanned 1.0 (thus were nonsignificant), except for leukemia, which had a total of 21 cases versus 13 expected, OR=1.62 and a CI of 1.04-2.52 (significant). Within the specific occupations, the largest OR (7.86, CI: 2.20-28.09) was for radio/television repair, thus apparently confirming the previous finding, but contrary to the previous finding for electricians, the OR (1.68, CI: 0.75-3.79) was nonsignificant. Also noteworthy was no excess of brain cancer (12 of 488 cases, OR=1.01, CI:0.56-1.82).

The authors also examined the leukemia incidences within five subtypes: acute lymphatic, chronic lymphatic, acute myeloid, chronic myeloid, and other for the two age groups 20-64 (9 cases total) and 65 years or older (12 cases total). The only significant excess was for chronic lymphatic leukemia (4 cases in the younger age group) rather than for acute myeloid leukemia, found in other studies.

The findings of this study are questionable for the same reasons as for the previous studies by these authors. In this paper, however, they did note that many comparisons involved small numbers.

Reif et al. (1989) also used the New Zealand Cancer Registry to analyze the incidences of brain cancer by major occupational category, and in three occupational subgroups. The highest incidence was in the subgroup comprised of agricultural workers, forestry workers, and fishermen, which had 79 cases, an overall OR of 1.38, and a CI of 1.08-1.77. The next highest incidence was in the subgroup consisting of professional, technical, and related workers, with an OR of 1.32 and a CI of 1.02-1.69 in a total of 74 cases. Of specific interest is that within the latter subgroup, the only significant brain-cancer excesses were for religious workers (9 cases, OR=4.27, CI: 2.26-8.09) and for statisticians, mathematicians, and systems analysts (4 cases total, OR=4.26, CI: 1.51-11.98). Within the third subgroup, production workers, which had a total of 185 cases, 8 cases were classified as electrical workers; the OR was 0.78, with a CI of 0.39-1.59 (nonsignificant). As with the other studies above of these authors, little credence can be given to either the positive or negative findings.

Thomas et al. (1987) analyzed the risk of brain tumor mortality for men occupationally exposed to RFR, lead, and soldering fumes in the petrochemical industry. The authors obtained death certificates of men who had died at age 30 years or older from brain tumors or other tumors of the central nervous system between 1 January 1979 and 31 December 1981 in northern New Jersey and in Philadelphia and its surrounding counties. They also acquired similar data for men who had died between 1 January 1978 and 30 June 1980 in the gulf coast of Louisiana. The lifetime work histories for the case men were obtained from next-of-kin. One control for each case was selected from men matched in age and year of death and area of residence, but who had died from causes other than brain tumor.

Case men were classified regarding RFR-exposure by two methods. In the first method, the men were divided into two job-related categories: those involved in design, manufacture, installation, or maintenance of electronic or electrical equipment; and those exposed to RFR in other types of jobs (such as welding and radio broadcasting). In the second method, a certified industrial hygienist assigned codes to each job in the lifetime occupational histories of the individuals for presumed exposure to: RFR, lead (high, moderate, or low), and soldering fumes (high or low). The authors noted that the classifications for RFR-exposure in the two methods overlapped considerably, but that the second method included men in supervisory jobs not considered exposed in the first method.

Information was available on 435 cases and 386 controls. Of the 435 cases, 300 had astrocytic tumors, 90 had other recognized types of tumor cell, and 45 had unknown types of tumor cell. The authors estimated the maximum-

likelihood relative risk (RR) and 95% confidence interval (CI) for each exposure and job category, and they adjusted the data for possible confounding influences of educational level. They regarded any RR greater than 1.0 as significant if its 95% CI did not span 1.0.

The analyses showed significantly elevated RRs for astrocytic brain tumor among the men classified as exposed to RFR in jobs involving design, manufacture, installation, or maintenance of electronic or electrical equipment. The RRs were not elevated for exposure to RFR in other types of jobs. The highest RR was for the combined classifications of engineers, teachers, technicians, repairers, and assemblers. The RR rose with exposure duration to tenfold for those in jobs associated with manufacture and repair of electronic equipment for 20 or more years, but the RR for "tradesmen" (combined categories of electricians, and power and telephone linemen) showed no consistent pattern with increasing employment duration. On the other hand, the values of RR were also higher for electronics workers classified as not having been exposed to RFR.

Elevated RRs were reported for those exposed to soldering fumes, but the variations with presumed exposure level were not large. However, nearly all of the men exposed to soldering fumes had such exposure in electronics manufacture and repair jobs. RRs were not elevated for exposure to lead by level (low, medium, high) or overall.

Based on those results, the authors suggested that simple exposure to MW/RF radiation was not the responsible agent for excess brain tumor risk, and they noted that exposure to such radiation in electronics jobs is probably intermittent and may be accompanied by exposures to lead, solder fluxes, solvents, and other chemicals. They also stated that the results should be interpreted with some caution, because when they calculated the risks for specific occupations and for individual strata by employment duration, they obtained very small numbers in single cells.

Archimbaud et al. (1989) reported on a 46-year old patient with acute myelogenous leukemia (AML) who, for about 22 years, had been repairing microwave generators of powers up to 3 kW in professional microwave ovens. During that period, he had repaired five to six generators a day for six days a week, and had tested each repair by switching on the unprotected generator for one minute. Thus, the patient estimated that his daily microwave exposure had been five minutes. The authors remarked that the patient had not been exposed to any known carcinogenic chemical in his employment.

The clinical tests performed on the patient that yielded the diagnosis of secondary AML were described in some detail. Various treatments of the patient, including two courses of chemotherapy and a bone-marrow allograft, were ultimately unsuccessful.

The authors remarked that: "Although exposure to microwaves is known to induce genetic damage in animal species [citing Roberts and Michaelson, 1983; Szmigielski et al., 1982] and in human lymphocytes *in vitro* [citing Stodolnik and Baranska, 1967], large epidemiologic studies of the potential role of microwaves in carcinogenesis have yielded negative results [Robinette et al., 1980]...However, populations studied were not intensely exposed to this type of radiation."

Jauchem (1990) took issue with the remark of Archimbaud et al. (1989) about the suggested involvement of RFR-exposure in their findings, noting the absence of measurements of the RFR levels or of any other details regarding the patient's exposure conditions. Also questioned were the statements about the genetic activity of microwaves and interpretation by the authors of the references they cited. Jauchem (1990) remarked: "Readers should exercise caution in making broad conclusions concerning the safety of exposure to microwaves on the basis of speculative and unsubstantiated reports."

Archimbaud (1990) responded to the comment of Jauchem (1990) about the genetic activity of microwaves by citing the studies by Garaj-Vrhovac et al. (1990), and Balcer-Kubiczek and Harrison (1989). [Garaj-Vrhovac et al. (1990) had reported that cultures of V79 Chinese hamster cells exposed to 7.7-GHz RFR at 30 mW/cm^2 for 30 minutes exhibited inhibition of tritiated thymidine uptake and higher incidence of chromosome aberrations than control cultures. Balcer-Kubiczek and Harrison (1989) had reported that 2.45-GHz RFR, together with a known chemical carcinogen (TPA), promotes neoplastic transformation in mouse-embryo-fibroblast-cell cultures, whereas the RFR alone does not. The findings of both of these studies have been questioned by others.] Jauchem (1991) also disputed other comments by Archimbaud (1990), including a statement that "microwave ovens used for cooking are known to leak during ordinary use".

Hocking and Garson (1990) also questioned the findings of Archimbaud et al. (1989) for reasons similar to those of Jauchem (1990), and added remarks about the absence of ocular effects in the patient and the negative findings of their cytogenetic study of 38 radiolinemen exposed at levels not exceeding the 1985 Australian standards (Garson et al., then in preparation, published in 1991).

In the Garson et al. (1991) study above, 40 volunteers were selected randomly from about 250 radiolinemen employed by Telecom Australia to erect and maintain broadcasting, telecommunication, and satellite RFR transmission towers, and were matched with 40 unexposed clerical personnel by age and Australian State. Each exposed subject had worked at least five of the previous six years, and had been last exposed no more than 12 months before the study. The exposure frequencies ranged from 400 kHz to 20 GHz. Before 1985, the exposure levels were within the ANSI (1982) guidelines; subsequently they were limited to the occupational levels of the 1985 Australian standard (AUS, 1985), which includes limits to avoid shock and burn. Specifically, the exposures of radiolinemen were limited to: 614 V/m and 1.63 A/m in the range from 400 kHz to 3 MHz, 61.4 V/m and 0.163 A/m between 30 MHz and 20 GHz, and intermediate frequency-dependent levels in the transition range 3-30 MHz. The authors noted that in recent dosimetric measurements of radiolinemen at sites operating at up to 100 MHz, the induced current flow in each leg was less than the specified 100 mA limit.

Heparinized blood samples (10 ml each) were drawn from each exposed and control subject on the same day and treated in the same manner to minimize any chromosomal damage from handling or culturing. Duplicate cultures from each sample were prepared, and 100 metaphases from each culture (200 metaphases per subject) were counted and assessed for chromosome damage in five categories: chromatid gaps, chromatid breaks, chromosome gaps, chromosome breaks, and "other" (more complex abnormalities). The specimens were randomly coded, and were analyzed blind by only one of the authors to minimize observer error. Of the 40 pairs of samples, two were discarded because one of each pair did not produce metaphases, leaving 38 pairs for analysis.

The authors assumed that chromosomal damage occurs at a given rate and that any specific abnormality occurs independently of any other abnormality of the same or different type in the same subject. The Poisson distribution was used for statistical analysis of the data from the matched subjects. The results of the analysis are summarized in Table 21 (adapted from Table 2 of the paper). The authors noted that one of the control subjects exhibited at least 30 chromatid breaks, 14 chromosome breaks, and 3 other aberrations, totaling at least 47 aberrations. The data for that subject were excluded as outliers, but were included in Table 21 without 95% confidence intervals.

TABLE 21: CHROMOSOMAL DAMAGE IN RADIOLINEMEN AND CONTROLS
[Garson et al. (1991)]

Type of Abnormality	Rate per 100 cells Exposed	Controls	Rate Ratio (95% Confidence Interval)
Chromatid gaps	0.54	0.46	1.2 (0.7-2.1)
Chromosome gaps	0.21	0.14	1.5 (0.6-3.5)
Chromatid breaks	0.20	0.61	
Without outlier	0.18	0.22	0.8 (0.3-2.0)
Chromosome breaks	0.95	0.88	
Without outlier	0.97	0.72	1.4 (0.8-2.3)
Other aberrations	0.63	0.64	1.0 (0.6-1.5)
Sum of aberrations	2.53	2.74	
Without outlier	2.55	2.18	1.2 (0.9-1.6)
Total aberrant cells	1.92	1.88	1.0 (0.8-1.3)

As seen in the table, most of the ratios of exposed-to-control rates slightly exceeded 1.0, but all of the 95% confidence intervals spanned 1.0, thus indicating that the differences between the exposed and control subjects were not significant ($p>0.05$). The authors, noting that smoking, recent infections, and X-rays were possible confounding factors, made adjustments for each such factor but not involving matched pairs (because of missing data on some subjects), and found that none of the factors materially altered the negative findings.

Hayes et al. (1990) did a case-control study of 271 individuals, age range 18-42 years, newly diagnosed with testicular cancer between 1 January 1976 and 30 June 1981, to determine the occupational risk of testicular cancer relative to other types of cancer. The cases including 60 with seminoma (a malignant neoplasm of the testis) and 206 with other germinal-cell tumors, and were referred for treatment to the Uniformed Services University Naval Hospital (USUNH), the Uniformed Services University Walter Reed Army Medical Center (WRAMC), or the National Institutes of Health Clinical Center (NIHCC). Many of the cases were military personnel on active duty. Those diagnosed before 1979 were ascertained from tumor registries, hospital admissions, and the urology and pathology records at the three centers, and were interviewed by telephone; those diagnosed between 1979 and 1981 were interviewed in the respective hospitals.

The controls were 259 patients diagnosed at the same centers with cancer in other than the genital tract. Those diagnosed between 1976 and 1978 were identified from the computerized discharge logs at NIHCC and WRAMC and the

tumor-registry records at USUNH, and were interviewed by telephone. Those diagnosed during 1979-1981 were identified on the oncology, surgical, and medical wards, and were interviewed in the hospitals. Also, mothers of the case and control individuals were interviewed by telephone.

Controls were diagnosed during the same time period, and were frequency-matched to the cases by age ± 2 years. The authors noted: "To assess the possibility of biased results due to the use of cancer controls, some analyses were carried out limiting the control series either to subjects with lymphatic and haematopoietic malignancies or to subjects with other cancers." Of 335 cases with testicular cancer, 308 were alive, and interviews were completed for 271 of them, a response rate of 88%. Of 288 controls selected, 259 were interviewed, a response rate of 90%. The study population was 98% white, with a mean age at diagnosis of 27 years for both groups.

Of the interviewed testicular-cancer cases, 266 (98%) had germinal-cell carcinomas, grouped as seminomas (60 cases) and all other germinal-cell tumors (206 cases), with major histological groups classified as embryonal carcinoma (69) and teratocarcinoma (67). Of the five remaining cases, three had non-germinal (Leydig-cell) tumors and two had testicular tumors of unknown type. Of the controls, 29% had Hodgkin's disease; 18% non-Hodgkin's lymphoma; 17% melanoma; 7% each of soft-tissue sarcoma, bone tumors, and leukemia; 4% nervous-system tumors; and 11% other cancers.

Information sought in the interviews included: job titles, activities and duties; materials handled; part-time or full-time status; name, type, and location of business; year started; and year ended. Also, the subjects were asked if they had been exposed to or handled: (1) radioisotopes, radioactive materials, nuclear materials; (2) radar equipment; (3) microwaves, microwave ovens, or other radio waves; (4) pesticides; or (5) polycyclic aromatic hydrocarbons. The authors stated: "Specific questions about exposure to electromagnetic waves were included to investigate an *a priori* clinical impression that radar and other microwave exposure were common among military testicular cancer cases."

The results were tabulated by occupation in terms of the odds ratios (ORs), with CIs (95% confidence intervals) and numbers of controls, for all testicular cancers combined, and by subdivision of the cases into seminomas and "other" germinal-cell carcinomas. The occupational titles shown were: professionals (divided into administrator, teacher, physician/veterinarian); other professionals; other white collar workers (non-professional: health related, engineer/science, other technician, sales/service, clerk); blue collar workers (agricultural/ farming/fishing, construction, mining, transportation, mechanics/repair; garage service, electrical/repair, other repair, production, other manual); ship employment; and aircraft maintenance.

Among the general findings was a significant elevation of risk (OR=2.8) for seminoma in all professional subcategories, and a nonsignificant excess risk in the other-white-collar category. No increased risk for seminoma was associated with the blue-collar occupations, and the risk was significantly lower for the agricultural, forestry and fishery, and construction workers.

The risk ratios for the five categories above of self-reported specific occupational exposures are tabulated in Table 22 (adapted from Table 3 of the paper). Particularly noteworthy are the results for category (3) "exposure to

TABLE 22: ODDS RATIOS* FOR TESTICULAR CANCER BY SELF-REPORTED EXPOSURE

[Hayes et al. (1990)]

				GERMINAL-CELL CARCINOMAS					
		ALL TESTICULAR (N=271)		SEMINOMA (N=60)			OTHER (N=206)		
Exposure	No. of Controls	OR	CI†	OR	CI†	No.	OR	CI†	No.
Radioactive materials	23	1.2	0.6-2.3	1.3	0.5-3.3	8	1.2	0.6-2.4	20
Radar equip.	38	1.1	0.7-1.9	1.3	0.6-2.8	12	1.1	0.6-1.9	30
Microwave/ Other radio	10	3.1	1.4-6.9	2.8	0.9-8.6	7	3.2	1.4-7.4	24
Hydrocarbons	12	1.5	0.7-3.4	1.0	0.2-3.9	3	1.7	0.7-4.0	15
Pesticides	29	1.2	0.4-1.2	0.1	0.0-1.0	1	1.5	0.9-2.7	32

*Odds ratios adjusted for age (16-21, 22-25, 26-29, 30-43)
†CI = 95% confidence interval

TABLE 23: ODDS RATIOS FOR TESTICULAR CANCER AMONG MILITARY PATIENTS BASED ON ASSESSMENT FROM JOB TITLE AND SELF-REPORTED EXPOSURE TO MICROWAVES AND OTHER RADIOWAVES

[Hayes et al. (1990)]

	EXPOSURE				
	None	Low	Medium	High	Any
Cases	116	10	6	12	28
Controls	107	4	6	14	24
OR	1.0	2.3	1.0	0.8	1.1
CI	---	0.6-9.4	0.3-3.8	0.3-2.0	0.6-2.1

microwaves or other radio waves": OR=3.1 (1.4-6.9 CI) for all testicular tumors, with OR=2.8 (0.9-8.6 CI) specifically for seminomas and OR=3.2 (1.4-7.4 CI) specifically for other germinal-cell carcinomas. Also, when only the subjects treated in the two military hospitals were considered, the OR for all testicular tumors was 3.5 with a CI of 1.3-10.2. The authors indicated that those elevations of risk were significant. On the other hand, the results for category (2) "radar equipment" were ORs of only 1.1 (CI: 0.7-1.9) for all testicular tumors, 1.3 (CI: 0.6-2.8) for seminomas, and 1.1 (CI: 0.6-1.9) for other germinal-cell carcinomas, all nonsignificant. Not clear is why the authors did not regard categories (3) and (2) as a single one.

However, the authors stated that an independent assessment of the self-reported exposures by job title did not support the significant elevations of risk for category (3). Specifically, an industrial hygienist classified the exposures of the military patients to radar or other microwaves as: high (e.g. electronic technicians and repairmen, power-generator and microwave-system operators), medium (e.g. communications operators and signal officers), or low (e.g. airplane flight crews). The results are displayed in Table 23 above (adapted from Table 4 of the paper). As seen therein, the largest OR (2.3) was for those classified as having had low exposure, and the OR for the high-exposure group was only 0.8.

Thus, the results of this study show no increase of risk of testicular cancer relative to other types of cancer from presumed occupational exposure to RFR, and provide neither positive nor negative evidence that any of the types of cancer suffered by the patients was due to chronic RFR-exposure.

In several of the epidemiologic studies discussed above, the occupations considered included those that may have involved exposure to frequencies in the RFR range as defined herein, as well as to frequencies below that range. Other studies of possible associations between cancer incidence and electrical occupations have been conducted, but largely of subjects presumably exposed to powerline fields or low-frequency power equipment of various kinds and with emphasis on the role of the magnetic fields. Analysis of such studies are outside the scope of this report, but may be the subject of another report by the authors.

2.5.1 SUMMARY ON RFR AND CANCER INCIDENCE

The findings of the various studies specifically directed toward seeking a possible relation between RFR-exposure of humans and cancer incidence are summarized in Table 24 (A, B, C, D, E, F, and G).

Authors	Effects Sought or Examined	Exposure Modality	Effects Reported	Notes & Comments
Lester and Moore (1982a)	Increased cancer incidence in areas surrounding U.S. Air Force bases (AFBs). The authors found 92 counties that had 1 or more AFBs, and matched each county with one of about the same population that had no AFBs.	RFR from the radars at AFBs. (Specific characteristics not given.)	The authors used a 1-tailed test for correlated proportions. They concluded that AFB counties, when compared with population-matched nonAFB counties, had a significantly higher cancer mortality incidence for the period 1950-1969, and suggested that the higher incidence was due to RFR-exposure from the radars.	The authors indexed the data on cancer mortality in each AFB and nonAFB county in terms of severity relative to cancer mortality in the general U.S. population. Their findings (if valid) do not confirm that the increased cancer mortality is associated with RFR-exposure, but only that such mortality may be correlated with the presence of an operating AFB.
Polson and Merritt (1985)	These authors carried out an independent reanalysis of the raw data provided by Dr. Lester on this study. The review of the raw data showed several inconsistencies, mostly in AFB location and counting, which were corrected.	See Lester and Moore (1982a).	Statistical treatment of the corrected data base showed that the incidences of cancer mortality in counties with AFBs for the period 1950-1969 did not differ significantly from the incidences in the nonAFB counties most closely matched in population.	In a response to Polson and Merritt (1985), Lester (1985) took issue with several aspects of the reanalysis and did not accept their finding of no significant differences in cancer-mortality incidence.
Lester and Moore (1982b)	The authors sought a possible geographic pattern of cancer incidence in Wichita, and whether specific RFR sources could be identified and related to any such pattern. Their analysis was based on morbidity data for first diagnosed cancer cases of Wichita residents for 1975, 1976, 1977.	The authors suggested that the radars at Wichita Mid-Continent Airport and McConnell AFB were the primary RFR sources, and they presented a formula relating incidence of cancer to terrain and exposure via line-of-sight transmissions to relatively high locations.	The authors selected 76 of the city's 94 census tracts, and assumed the incidence rates for the 76 census tracts to be the ratio of the number of cases in each tract to its population. They also obtained mortality data for all cancer deaths in those years, and analyzed incidence rates, age, economic status, male/female ratio, and race to obtain a correlation matrix for those 76 census tracts. Their finding was that cancer incidence in Wichita appears to be related to the probability of exposure to the RFR from the radars at the two airports.	This paper contains a number of flaws, among them the assumption that the population is exposed only to the RFR from radars at the two airports adjacent to the city, without providing measurements to support the assumption or any indication that the scan sectors of such radars were considered. Moreover, their exposure formula was not based on the physical laws of RFR propagation, most particularly the inverse-square-law of attenuation with distance. Thus, little if any credence can be given to their finding.

TABLE 24A: RFR AND CANCER INCIDENCE

Authors	Effects Sought or Examined	Exposure Modality	Effects Reported	Notes & Comments
Milham (1982)	Leukemia in men from presumed occupational exposure to electric and magnetic fields in Washington State for the years 1970-1979. The author determined the number of deaths from each of 158 causes in each of 218 coded occupations.	No exposure data were given; assumption of field exposure was based on 11 of 218 occupational codes.	The PMRs for 7 of the 11 assumed field-exposure occupations were marked by the author as not statistically significant. For the remaining 4 occupational codes, (electricians, television and radio repairmen, power-station operators, and aluminum workers), 3 of the PMRs for "all leukemia" were marked significant; the exception was for the television and radio repairmen. Three of the PMRs for "acute leukemia" in those 4 occupations were also marked significant, but the nonsignificant exception was for power-station operators.	The author used the ratio of the number of deaths from each cause in each occupation to the expected number of deaths from that cause, multiplied by 100, called the "proportionate mortality ratio" (PMR). He surmised that the leukemia findings were associated primarily with exposures to large dc currents and high alternating electric and magnetic power fields. Liburdy (1982) disagreed with those findings, citing several references that do not support the leukemia association.
Wright et al. (1982)	Leukemia in men from presumed occupational exposure to electric and magnetic fields during 1972 to 1979, as determined from the Cancer Surveillance Program in Los Angeles County.	No exposure data were given.	A trend toward a higher risk of leukemia from occupational exposure to electric and magnetic fields was reported, with the greatest risk for acute myelogenous leukemia (AML).	The authors used proportional incidence ratios (PIRs) for the data in the Los Angeles County Cancer Surveillance Program. The authors remarked that the subjects may also have been exposed to metal fumes, solvents, fluxes, chlorinated biphenyls, synthetic waxes, epoxy resins, and chlorinated naphthalenes, a point that render the findings highly questionable.
McDowall (1983)	PMRs for occupational mortality in England and Wales during 1970 to 1972 in males 15-72 years of age. A case-control study of the deaths of 537 males from AML in the year 1973, with 1074 male deaths from all causes except leukemia as controls.	No exposure data were given.	The PMR study showed that the mortality distribution for all leukemias did not differ significantly from expected, but the PMRs for AML were significantly higher than 100 for self-described electrical engineers, telegraph radio operators, professional electrical engineers, and professional electronic engineers. The results for the case-control study showed significantly elevated relative risks (RRs) for the electrical occupations, with the highest RR for telecommunications engineers.	It is noteworthy that the PMRs for occupations that may have involved exposure to RFR (as defined herein) ranged from a low of 61 for radio and radar mechanics to a high of 249 for telegraph radio operators. However, as with other studies in which the PMR statistic was used, both the positive and negative findings of this study are open to question.

TABLE 24B: RFR AND CANCER INCIDENCE (CONTINUED)

Authors	Effects Sought or Examined	Exposure Modality	Effects Reported	Notes & Comments
Coleman et al. (1983)	leukemia incidence in males of ages 15-74 years in 10 electrical occupations in South-East England during 1961-1979. The authors remarked that the South Thames Cancer Registry for 1961-1979 listed about 30,000 tumors per year in a population of 6.5 million; proportional registration ratios (PRRs) for leukemia were calculated in the males therein.	No exposure data were presented.	Found was a 17% excess of all leukemias in all electrical occupations (PRR=117, $p<0.05$). However, although 8 of the 10 occupations showed excesses, there was an all leukemia deficit (PRR=22, $p=0.07$) for "radio/radar mechanics". The PRRs for all of the electrical occupations also showed no overall excess of chronic myeloid leukemia, but a 46% excess of acute lymphoid leukemia, a 29% excess of chronic lymphoid leukemia, and a 23% excess of acute myeloid leukemia (AML). The excesses of AML were in 7 of the 10 occupations, but not all the excesses were significant, and there were no cases in the occupations "radio/radar mechanics" or "professional electronic engineers".	The authors' null hypothesis was that the proportion of leukemic men in each 5-year-age group in each electrical occupation would be the same as the proportion of the men with leukemia in all occupations. The results show no evidence of excess leukemia associated with those occupations that may involve exposure to RFR.
Milham (1983)	The author gathered decedent data for the years 1974-1979 in Washington State, and analyzed the causes of death for 219 male and 51 female occupations. His report contained commentaries that described mortality patterns in each of the male and female occupation groupings.	The author suggested that some occupations may have involved exposure to electric and/or magnetic fields.	Some commentaries appear to be highly subjective and to reflect the personal biases of the author. On only one page of the report, 11 categories of workers presumed to be occupationally exposed to magnetic or electrical fields were grouped, and PMRs for two leukemia categories (acute leukemia, and all leukemia) were presented. Significantly high PMRs were reported for 5 of the 22 occupational/leukemia categories, but were probably significant because PMRs in some other categories were abnormally low. Thus, the association found between leukemia and exposure to electric and/or magnetic fields is questionable.	Described were the occupation codes used in preparing death certificates, the occupation groupings for women, and the occupation indexes for men and women. The author used the "proportionate mortality ratio" (PMR), making their values interdependent. Use of the "standardized mortality ratio" (SMR) would have been more appropriate; it indicates the percentage of deaths for each cause to the expected number of deaths from that cause, independent of any other SMR.
Milham (1985)	Mortality data on the male members of the American Radio Relay League (operators of amateur radios) listed as decedents in QST, the monthly magazine of the League.	No specific exposure data were presented. The author noted that some ARRL members may also have been in occupations involving RFR-exposure.	The PMR was 281 for acute, chronic, and unspecified myelogenous leukemia; the PMR for monocytotic leukemia was only 77 (well below 100), and there were no cases of lymphatic leukemia. Thus, the PMR for all leukemias was 191 (24 deaths versus 12.6 deaths expected, $p<0.01$).	Death certificates for 1971-1983 were obtained for 280 decedents in the State of Washington, and information on the age, date, and cause of death was obtained for 1411 decedents in California. PMRs were calculated for specific and all leukemias. As noted previously, the use of the PMR statistic is questionable.

TABLE 24C: RFR AND CANCER INCIDENCE (CONTINUED)

Authors	Effects Sought or Examined	Exposure Modality	Effects Reported	Notes & Comments
Wangler et al. (1985) Coleman (1985)	For several reasons, Wangler et al. (1985) took issue with the Milham (1985) finding of a higher risk of leukemia in amateur radio operators. Coleman (1985) did not agree with most of the comments by Wangler et al. (1985).	See Milham (1985).	See Milham (1985).	Wangler et al. (1985) cited a 1980 survey in Canada and the U.S. that showed that typical amateurs spent 6.1 hours per week on that activity, much of which was highly variable and most of which was listening, with the remainder involving intermittent transmissions at low average radiated powers. They also questioned the statistical treatment used.
Milham (1988a)	Mortality in amateur radio operators due to RFR-exposure from their transmitters. The author obtained the names of 67,829 males licensed in California and the State of Washington, and searched them for deaths during 1979-1984, which yielded 2,485 decedents taken to have had 232,499 person-years at risk.	Specific frequencies were not indicated, but presumably were in the FCC-approved amateur bands.	Unlike in his previous studies, Milham (1988a) used the SMR. For "all malignant neoplasms," the SMR was 89 with an 82-95 CI, a significantly lower death rate than for the general population. The SMR for the subcategory "other lymphatic tissue" of malignant neoplasms was 162 with a CI of 117-218, a significant excess. Also examined were 9 leukemia subdivisions or sub-subdivisions. Of 36 deaths, 15 were for "acute myeloid" leukemia versus 8.5 of the expected 29. The SMR was 176 with a CI of 103-285, also a significant excess.	An SMR that exceeds 100 with a 95% confidence interval (CI) entirely above 100 is deemed a significant increase; an SMR less than 100 with a CI below 100 is a significant decrease. Little credence can be given to the significant excesses found, in view of the small numbers of deaths relative to the actual and expected totals.
Milham (1988b)	Mortality in amateur radio operators in the 5 FCC-license classes: novice, technician, general, advanced, and extra.	Specific frequencies were not indicated, but presumably were in the FCC-approved amateur bands.	The numbers of deaths and SMRs in each class from all causes, all malignant neoplasms, and various specific types of malignancies were tabulated. The SMRs for all death causes were significantly below 100. For deaths from all malignant neoplasms, the SMRs for all 5 license classes were below 100, but the collective SMR for the malignant-neoplasms category was 89. The SMRs for lymphatic and hematopoietic neoplasms exceeded 100, but the only significant excess was for the technician-license class. Also, except for the novice class, the SMRs for multiple myeloma and other lymphomas exceeded 100, but the excess was significant only for the general-license class.	No confidence limits were shown, but the significant SMRs were so marked. In both the technician-license and general-licence classes, for which significant excesses were reported, the numbers of deaths were small: 18 of 409 deaths in the former class and 15 of 862 deaths in the latter class.

TABLE 24D: RFR AND CANCER INCIDENCE (CONTINUED)

Authors	Effects Sought or Examined	Exposure Modality	Effects Reported	Notes & Comments
Pearce et al. (1985) Pearce (1988)	From a case-control study of 546 male leukemia patients for association with various agricultural occupations in New Zealand (NZ), Pearce et al. (1985) sought an association with several specific occupations that may have involved exposure to electric and/or magnetic fields.	The patient data for the study were drawn from the NZ Cancer Registry. Tabulated from the case-control study were leukemia odds ratios (ORs) and 95% confidence limits (CIs) for patients in 10 occupational classes, a total of 18 of the 546 cases. The controls were 43 of the 2,184 controls in thelarger study. No data were given on actual exposures to electric or magnetic fields.	Significant leukemia excesses were shown for electronic equipment assemblers, and in the radio/television repair category. The authors suggested that the excesses were due to exposure to nonionizing radiation or to metal fumes and other substances used in electrical components or their assembly. Several corrections were given in Pearce (1988), primarily that the excesses should have been ascribed to the radio/television repair and electricians occupations, and that there were no cases in the electronic equipment assemblers category.	The findings are questionable from a statistical viewpoint, primarily because of the small numbers of cases.
Pearce et al. (1989)	A case-control study of 488 patients in recorded electrical occupations out of 19,904 male patients with all types of cancer.	No data were given on actual exposures to electric or magnetic fields.	Of the 22 sites tabulated, 11 had ORs less than 1 and the other 11 had ORs in the range 1.0-1.62. However, all of the latter sites had CIs that spanned 1.0 (nonsignificant), except for leukemia, which had 21 cases versus 13 expected, OR=1.62, CI 1.04-2.52. In the specific occupations, the largest OR was for radio/television repair, in consonance with the previous finding for that occupation, but the OR for electricians was not significant, in contrast to the previous finding. For the five leukemia subtypes studied, the only significant excess was for chronic-lymphatic rather than acute-myeloid leukemia reported in other studies. Also noteworthy was no excess of brain cancer.	The controls for the patients with cancer at any specific site or cancer type consisted of those with cancer at other sites. The findings of this study are questionable for the same reasons as for the previous studies by these authors. In this paper, moreover, they did note that many comparisons involved small numbers.
Reif et al. (1989)	Incidences of brain cancer by major occupational category, and in 3 occupational subgroups.	The patient data were also drawn from the New Zealand Cancer Registry.	Highest incidence of brain cancer was for "agricultural workers, forestry workers, and fishermen," with an overall OR of 1.38 and a CI of 1.08-1.77. Only within the third-highest-incidence subgroup, "production workers," were there 8 of 185 cases classified as "electrical workers"; with an OR of 0.78, and a CI of 0.39-1.59.	As with the other studies of these authors, discussed above, little if any credence can be given to either the positive or negative findings.

TABLE 24E: RFR AND CANCER INCIDENCE (CONTINUED)

Authors	Effects Sought or Examined	Exposure Modality	Effects Reported	Notes & Comments
Thomas et al. (1987)	Brain tumor mortality from occupational exposure of men who had died at age 30 or older from brain tumors or other tumors of the central nervous systems.	Job categories or job codes were assigned to occupational histories to assess presumed exposure to: RFR, lead, and soldering fumes.	Data were obtained about men who had died from tumors during a 3-year period. One control for each case was selected from men matched in age and year of death and area of residence, but who had died from other than brain tumors. Of 435 cases, 300 had astrocytic tumors, 90 had other types of tumor cell, and 45 had unknown types of tumor cell. Highest relative risk (RR) was for the combined categories of engineers, teachers, technicians, repairers, and assemblers. Significant RRs were also reported for those exposed to soldering fumes.	The authors remarked that RFR was not the responsible agent because those exposed to RFR also may have been exposed to lead, solder fluxes, solvents, and other chemicals.
Archimbaud et al. (1989)	Clinical examination of a cancer patient presumed to have been exposed to high RFR levels.	From repair of 5 to 6 high-power microwave generators daily for 22 years and testing each by turning it on unshielded for 1 min (totaling about 5-6 min/day).	The diagnosis was acute myelogenous leukemia (AML), and was ascribed to the RFR-exposure. Various treatments of the patient, including two courses of chemotherapy and a bone-marrow allograft, were ultimately unsuccessful.	The association with RFR was questioned by Jauchem (1990) and by Hocking and Garson (1990), based on the lack of measurements of the RFR levels or any other details about the patient's exposure conditions.
Jauchem (1990) Hocking and Garson (1990) Archimbaud (1990)	Jauchem (1990) and Hocking and Garson (1990) questioned the findings of Archimbaud et al. (1989) for similar reasons. Archimbaud (1990) was a response to Jauchem (1990).	See Archimbaud et al. (1989).	See Archimbaud et al. (1989).	In addition to remarking the absence of measurements of the RFR levels or of any other details about the patient's exposures, Jauchem (1990) also questioned the remarks about genetic activity of microwaves and the interpretation by the authors of the references they cited. In response to Jauchem, Archimbaud (1990) cited the findings of several studies, but those studies were questioned by others. Hocking and Garson (1990) noted the absence of ocular effects in the patient and the negative findings of their cytogenetic study of 38 radiolinemen [Garson et al. (1991)].

TABLE 24F: RFR AND CANCER INCIDENCE (CONTINUED)

Authors	Effects Sought or Examined	Exposure Modality	Effects Reported	Notes & Comments
Garson et al. (1991)	Blood-sample analyses of 38 Australian radio linemen for chromosome damage, and of 38 controls matched in age and Australian State.	The subjects erected and maintained towers for broadcasting, telecommunication, and satellite RFR transmission. The exposure frequencies ranged from 400 kHz to 20 GHz; the levels were below the ANSI 1982 guidelines and the Australian 1985 occupational exposure guidelines.	From a statistical analysis based on the Poisson distribution, most of the ratios of exposed-to-control rates exceeded 1.0 slightly, but all of the 95% confidence intervals spanned 1.0, indicating that the differences between the exposed and control subjects were not significant ($p>0.05$).	Duplicate blood samples from each subject were cultured, and 100 metaphases from each culture were counted and assessed for chromatid gaps, chromatid breaks, chromosome gaps, chromosome breaks, and "other" abnormalities. The results for the exposed and control groups were tabulated in terms of the rates per 100 cells for each abnormality, the ratios of the rates for the two groups, and the 95% confidence intervals thereof.
Hayes et al. (1990)	A case-control study of 271 patients in 3 medical centers who were newly diagnosed as having testicular cancer, to determine the occupational risk for that type of cancer relative to other types. The controls were 259 patients diagnosed at the same centers with cancer in other than the genital tract.	In patient interviews about occupational activities, they were asked about exposure to or contact with various materials and equipments as sources of ionizing and/or nonionizing radiation and to pesticides or polycyclic aromatic hydrocarbons.	A general finding was a higher risk for seminoma (OR=2.8) in all professional subcategories. No increased risk for seminoma was associated with the blue-collar occupations, and the risk was significantly lower for agricultural, forestry-and-fishery, and construction workers. Noteworthy are the results for "exposure to microwaves or other radio waves": OR=3.1 (1.4-6.9 CI) for all testicular tumors. Also, when only the subjects treated in the 2 military hospitals were considered, the OR for all testicular tumors was 3.5 with a CI of 1.3-10.2. Similar results were shown for seminomas and "other" germinal-cell carcinomas. However, for the category "radar equipment," the OR for all testicular tumors was only 1.1 with a CI of 0.7-1.9 (nonsignificant). It is not clear why the authors did not regard the categories "exposure to microwaves or other radio waves" and "radar equipment" as a single one.	Two of the 3 medical centers were military hospitals, and many of the patients were military personnel on active duty. Results were tabulated by occupation in terms of the odds ratios (ORs), CIs, and numbers of controls, for all testicular cancers combined, and by subdividing the cases into seminomas and "other" germinal-cell carcinomas. The authors also presented an independent assessment by an industrial hygienist that did not support the higher risk for the category "exposure to microwaves or other radio waves". Thus, the results do not show an increase of risk of testicular cancer relative to the other types of cancer from occupational exposure to RFR, and do not provide either positive or negative evidence that the other types of cancer suffered by the patients was due to chronic RFR-exposure.

TABLE 24G: RFR AND CANCER INCIDENCE (CONCLUDED)

2.5.2 CONCLUSION

Various epidemiologic studies have been directed specifically toward seeking a possible association between RFR-exposure and cancer. The Lester and Moore (1982a) study of cancer incidence near Air Force bases (AFBs) was found to be flawed by Polson and Merritt (1985) because the authors had assembled a faulty data base; on correcting the data base, Polson and Merritt (1985) found no association of cancer in populations living in the vicinity of "radar" AFBs. The Lester and Moore study (1982b) of cancer incidence from the radars at Wichita Mid-Continent Airport and McConnell AFB was also flawed for several reasons, but basically because their formula for assessing population exposure to RFR was not based on physical laws of RFR propagation.

The findings of Milham (1982) of leukemia from presumed occupational exposure to electric and magnetic fields were questioned by Liburdy (1982), based on citations to studies that do not support those findings. The Milham (1982) findings are also questionable because of use of the "proportionate mortality ratio" (PMR) rather than a more appropriate statistic such as the "standardized mortality ratio" (SMR). Similar conclusions are applicable to the leukemia studies of Wright et al. (1982) and McDowall (1983). In none of those studies were any data presented on measured or estimated exposure levels or durations. Some excess risks for leukemia in electrical occupations were reported by Coleman et al. (1983), but there were no leukemia cases in the occupations "radio/radar mechanics" or "professional electronic engineers".

The findings of the more extensive Milham (1983) study of decedent data in the State of Washington are also questionable because of use of the PMR and because of possible personal bias of the author regarding the subjects in the various occupations.

The Milham (1985) study of deceased amateur radio operators reported a significant excess of leukemia deaths, but the numbers of cases were small (24 of 280 decedents versus 12.6 expected deaths), and as before, the use of the PMR is questionable. Also, Wangler et al. (1985) disagreed with the Milham (1985) findings, primarily because of the short time intervals spent by most amateur radio operators in actually transmitting, and the low average radiated powers during transmission. However, Coleman et al. (1985) disagreed with the Wangler et al. (1985) comments.

Milham (1988a, 1988b) used the SMR in the studies of decedent amateur radio operators, but little credence can be given to the findings because the numbers of deaths were small relative to the actual and expected totals.

The case-control studies of Pearce et al. (1985) and Pearce (1988) of leukemia patients yielded significant leukemia excesses for those in the occupations "radio/television repair" and "electrician," but the small numbers of cases render the findings questionable. A similar conclusion is applicable to Pearce et al. (1989) and Reif et al. (1989), the other studies by those authors. On the other hand, although the Thomas et al. (1987) study of cancer decedents yielded a statistical association of tumor incidence with their occupational histories, the authors did not regard RFR as the responsible agent because the subjects also may have been exposed to potential chemical carcinogens.

The Archimbaud et al. (1989) finding of an association of acute myelogenous leukemia (AML) in a patient who had repaired high-power microwave generators and tested them unshielded was criticized by Jauchem (1990) and Hocking and Garson (1990), primarily because of the absence of measurements of the RFR levels or any other specifics about the patient's exposure conditions. On the other hand, the Garson et al. (1991) study of radiolinemen for possible chromosomal damage from chronic RFR-exposure at levels within the ANSI (1982) and Australian exposure guidelines (AUS 1985) yielded negative findings.

In the case-control study by Hayes et al. (1990) of primarily military patients with testicular cancer, higher risks were reported for seminoma and "other" germinal cell carcinomas in various occupational categories, including patients with presumed "exposure to microwaves or other radio waves," but no excess risk for those in the "radar equipment" occupation. Why the authors regarded those two occupational categories as distinct is unclear. Moreover, an independent risk assessment by an industrial hygienist presented by the authors did not support their finding of higher risk.

Thus, the epidemiologic and other human studies above that sought an association between cancer and RFR-exposure do not provide scientifically credible evidence that chronic exposure to levels below the ANSI/IEEE (1992) exposure guidelines induces or promotes cancer. It should be noted, however, that cancer has been reported in some studies from exposure to magnetic fields at powerline frequencies (50 or 60 Hz), but that such findings were not confirmed in other studies. Pending the results of further studies, those positive and negative findings at powerline frequencies remain controversial. In this context, frequencies in the RFR range as defined herein (3 kHz to 300 GHz) are 50 to 5 billion times higher than 60 Hz. Thus, whatever the outcome of the powerline controversy, the findings thereof would not likely be applicable to whether RFR-exposure induces or promotes cancer, because of the basic, highly-frequency-dependent differences in the dielectric properties and physical mechanisms of interaction of electromagnetic fields with biological entities.

2.6 RFR-EXPOSURE FROM VIDEO DISPLAY TERMINALS

Reports have been published that pregnant women who occupationally use visual display terminals (VDTs) could be at risk for miscarriage or birth defects. Factors such as poor ergonomic conditions, job-related stress, and exposure to ionizing radiation have been considered, but chronic exposure to the nonionizing radiation emitted from such devices also has been suggested as a potential cause, as discussed below.

Weiss and Petersen (1979 determined the electromagnetic emissions from eight representative VDTs used by the (then) Bell System. Measurements were made of electric field strength (E) and/or power density in the continuous frequency band from 10 kHz to 18 GHz in the RF and microwave regions, spectral irradiance in the wavelength band from 350 to 600 nanometers in the visible and ultraviolet (UV) regions, and for possible leakage of X-rays. The units were: a Computer Consoles Model 128; a TEC Series 400, CRT 455; a Conrac Model SNA 23; an IBM 3275 Display, Dataphone 4800; a Tektronix 4014.1 CRT Display; a Digital Graphics Model 21 Terminal; a DAS.103 CRT Terminal; and a VYDEC 1200 Video Typewriter.

The RF and microwave measurements were done with an appropriate antenna placed about 1.5 meters in front of the terminal. The results were presented in four tables, which included the total RMS electric-field strength for each unit. The authors remarked that with the exception of the Digital Graphics terminal and the Tektronics display unit, measurable levels occurred only at frequencies up to about 150 MHz, and that a number of small signals in the hundreds of MHz were detected for the two exceptions. In addition, a 1.4-GHz signal was associated with the computer and not the display terminals in the same room. The authors also stated that in all cases, the total RMS electric-field strengths were well below the most stringent exposure standard in the world.

The irradiance measurements in the UV region were done at a distance of about 0.5 meter from the faceplate of the cathode ray tube, the approximate normal viewing distance. The results were displayed in two other tables. They indicated that the UV exposure levels were well below those recommended in the 1972 National Institute for Occupational Safety and Health criteria document (NIOSH, 1972).

Regarding X-ray emissions, the authors stated: "Although many video computer terminals have been examined for X-ray emissions no ionizing radiation was ever detected above the ambient background radiation level in the general area where the device was located." They listed the 11 types of CRTs examined; of those, only a Conrac Color TV monitor yielded levels above background (but less than 0.5 mR/hr, the maximum allowable level from TV receivers). The cause was a faulty high voltage power supply; the external radiation disappeared when the unit was repaired. A subsequent but briefer account of such measurements was presented in Petersen et al. (1980).

Stuchly et al. (1983) surveyed 86 VDTs, including 57 models manufactured by 25 firms (tabulated in the paper). The electric field intensities in the frequency range from 15 to 150 kHz, due to stray fields from the fly-back transformer, were measured with a commercial broadband survey meter at: the site of maximum intensity (always found at the outer casing of the VDT), the operator position (defined as 30 cm in front of the center of the VDT screen), and the location of the highest level at the keyboard.

Since various units of the same model yielded the same results, only the results for the various models were discussed. No actual measurement data were presented, but the authors indicated that the results for the operator position were less than 1 V/m for 37 models (65%) and ranged from 1 to 5 V/m for the other 20 models (35%). The keyboard results indicated that the highest level at any keyboard was 7 V/m, and that the levels exceeded 5 V/m for only 4 models (7%). Also, the levels were below 1 V/m for 33 models (58%) and between 1 and 5 V/m for the other 20 models (35%).

The authors tabulated the results for four ranges of intensity in terms of the number of models and the location of the highest level at the screen, top, sides, or back within each range. Ten of the models had maximum levels below 5 V/m, of which 5 had their highest level at the screen and the other 5 had levels too small to measure. Twenty-two models had maximum levels in the range 5-60 V/m; with highest level for 19 models at the screen, 1 at the top, and 2 at the sides. Ten models had maximum levels in the range 60-200 V/m, 7 with highest levels at the screen, 2 with highest levels at the sides, and 1

with highest level at the back. There were 15 models with levels exceeding 200 V/m, with highest level for 5 at the top, 5 at the sides, 2 at the back, and 3 at the screen. For the 3 models that had maxima at the screen, the level at 10 cm from the screen dropped to less than 70 V/m.

The authors also tabulated the spatial-average and maximum SARs in a prolate spheroidal human model exposed to plane waves at 10, 20, 50, 100, and 200 kHz at a field intensity of 1 V/m, with the long axis parallel to the field, based on Johnson et al. (1975). The highest spatial-average and maximum SARs were 0.000017 and 0.005 W/kg, both at 200 kHz, with the maxima at the surface of the model facing the source.

Nurminen and Kurppa (1988) studied 1,475 matched case-referent pairs of pregnant women from a Finnish study of occupational exposures and congenital malformations (compiled in the Finnish Register of Congenital Malformations), to determine whether office work, and particularly work involving use of VDTs during pregnancy, affected the pregnancy outcomes. The reference mothers were selected from those with deliveries immediately preceding the deliveries by the case mothers in the same maternity welfare district, but stillbirths or malformations were excluded. Also excluded were twin births. Those selected were regarded as representing a random sample of non-case mothers stratified by year of delivery for the years 1976-1982.

The case and referent mothers were interviewed regarding their work conditions and their various occupational and leisure-time activities, but no specific questions were asked about VDT work. Instead, occupational titles were used to recognize the mothers in office work with potential VDT usage, which yielded 255 of the 1,475 mothers. Of those, 239 had worked during their pregnancy and had singleton births. Their VDT exposures were assessed by an industrial hygienist and two experts in industrial medicine from descriptions of each mother's workday; 64 of the 239 were assessed as exposed. Average exposure times per workday were grouped as follows: 4 hours or more (33), less than 4 hours but at least 1 hour (10), and less than 1 hour (21). Of those 1,220 mothers not potentially VDT-exposed, 805 had performed non-office work during most of pregnancy and had singleton births.

Of the 239 mothers above with potential VDT usage, 8.4% had had symptoms of threatened abortion as compared with 9.8% of the 805 mothers in non-office work, a nonsignificant difference. Also nonsignificant was the difference in percentages of mothers who reported bleeding, pain, or both during pregnancy (20% versus 21.9%, respectively). The mothers in office and non-office work had similar proportions of preterm, term, and prolonged pregnancies, and there were no significant differences in neonate birth weights.

The authors concluded that they had found no indication of work-related reproductive problems in office environments in general or in VDT work in particular, but recognized that the smallness of the VDT group precluded more detailed analyses of possible differences between the groups. Similar negative findings had been reported by Kurppa et al. (1985), an earlier study.

McDonald et al. (1986) used interviews by bilingual nurses to obtain information about 56,012 women in 11 Montreal hospitals after a delivery or a spontaneous abortion during the period 11 May 1982 to 10 May 1984 (covering approximately 90% of all Montreal births). The women were also questioned

about previous pregnancies, 48,608 in all, for a total of 104,620 pregnancies. Data on admissions for spontaneous abortions could be obtained on only about 75% of such cases; the authors estimated that the sample was less than half of the total of spontaneous abortions during that period, and may not have been wholly representative.

Data on congenital defects in current pregnancies were derived from medical records of pediatric examinations done before hospital discharge. Defect incidences in previous pregnancies were ascertained by questioning the mothers about physical or mental abnormalities of their children, and the defects were classified from information acquired from doctors and hospitals. Therapeutic abortions for malformed fetuses were included as defects.

Of the 56,012 women in current pregnancy, 25,418 (45.4%) were in paid employment for 30 or more hours a week at pregnancy start; of the 48,608 women with prior pregnancies, 22,697 (46.7%) were similarly employed. Referring to the time when the woman first became aware of being pregnant, among the many questions asked were: "Did your work include the regular use of a VDU [video display unit]? If 'yes', for how many hours a week?" The authors selected a series of occupational groups to distinguish VDU users from nonusers in two stages. First, they sought broad occupational categories in which VDU use for at least 15 hours a week had been reported in 5% or more of current or past pregnancies, which yielded the occupational categories "professional" and "clerical". They then excluded the subsectors of those categories with less than such usage, such as women in the educational field, which yielded 9,471 pregnant women (8,660 clerical and 811 professional). Similarly selected were 8,161 (593 clerical and 7,568 professional) of the 48,608 women with previous pregnancies.

The numbers of congenital birth defects from the current pregnancies of users of VDUs were tabulated for 10 major defect categories and compared with the expected numbers for those categories in the current pregnancies. In a total of 8,805 current pregnancies comprising both users and nonusers of VDUs, there were birth defects in 311 pregnancies (3.5%); of 3,257 VDU users in the 8,805 pregnancies, there were birth defects in 108 pregnancies (3.3%). The highest number of observed defect cases was for the category "musculoskeletal defects" (28 cases), a number lower than the expected value (33.3 cases). The next highest incidence was for the category "renal-genital defects", for which there were 22 cases versus 20.0 expected, one of the two categories in which the number of cases observed was higher than the expected value. The other was "chromosomal defects", in which there were 6 cases versus 4.4 expected.

The results for the previous pregnancies were similarly tabulated. The numbers were smaller, but the percentages were comparable: 50 defects in 1,301 pregnancies of VDU users (3.8%); 236 defects in a total of 6,455 pregnancies of users and nonusers (3.7%). In addition, the observed values exceeded their expected values in 5 of the 10 categories. The authors concluded that in VDU users, there was no excess in the overall rate of defects or in any specific defect category.

The results on spontaneous abortion were less clear. One potentially confounding factor was the rapid rise in the use of VDUs during the period studied, which would yield a spurious association between such use and spontaneous abortion incidence if previous pregnancies by year of conception

were not analyzed and if other factors were not considered, such as the effects of age, number of previous pregnancies, and cigarette smoking on abortion risk. The authors used logistic regression to estimate the allowance to be made for such potentially confounding factors by using separate models for current and previous pregnancies.

The results for the previous pregnancies yielded no evidence for an association between VDU usage and spontaneous abortion incidence, but the findings for abortions in the current pregnancies were equivocal. Those results are displayed in Table 25 (adapted from Table 3 of the paper), in which the data on the number of pregnancies, the numbers of observed (O) and expected (E) spontaneous abortions, the ratio O/E, the 90% confidence interval (CI), and probability (p) are given for ranges of VDU usage in hours a week.

TABLE 25: RATIOS OF OBSERVED (O) AND EXPECTED (E) NUMBERS OF SPONTANEOUS ABORTIONS IN CURRENT PREGNANCIES

[McDonald et al. (1986)]

VDU Use hrs/week	Pregnancies	Observed (O) Abortions	Expected (E) Abortions	O/E	90% CI	p
None	5,904	356	398.9	0.89	0.82-0.97	0.01
1-6	1,161	94	78.8	1.24	1.04-0.97	0.02
7-29	1,361	112	89.3	1.25	1.07-0.97	0.01
≥30	1,016	75	66.7	1.12	0.92-1.35	0.16
Total*	9,442	637	630.7	1.01	0.95-1.08	0.40

*Excluding 29 pregnancies in which use of a VDU was unknown.

As seen above, the ratio of observed to expected spontaneous abortion cases (O/E) in the current pregnancies slightly exceeded 1.00 for all usages except none, but with 90% CIs for both the least (None) and most (≥30 hours a week) usage that spanned 1.00, rendering them nonsignificant. Also noteworthy is that the percentage of observed abortions was 6.0% (356/5904) in the zero-use group and was somewhat higher, 7.4% (75/1016), in the highest usage group, but that the numbers of cases were about 20% of those in the former group. Regarding the total numbers, the sum of the expected abortions is 633.7, not 630.7 as shown in the table; the new value is closer to the total number of observed abortions (637) than the old. Thus, those data do not support an association between VDU use and the incidence of spontaneous abortion, a finding concluded by the authors as well. Why 90% confidence intervals were used rather than the more conventional 95% confidence intervals is unclear.

In McDonald et al. (1988), the women in Montreal hospitals who had been interviewed during the period 11 May 1982 to 10 May 1984 and their pregnancy outcomes analyzed in the previous study (plus a few additional cases: 104,649 versus 104,620 total current and previous pregnancies) were reanalyzed. The later paper also included information on the incidences of stillbirth and low birthweight as well as spontaneous abortion and congenital defects. The main statistical method used was to enter confounding variables for each outcome [7 variables for spontaneous abortion and stillbirth (age, gravidity, previous miscarriage, ethnic group, educational level, smoking, alcohol consumption)] into a logistical regression analysis, calculate the probabilities of those outcomes from the regression coefficients, use the coefficients to calculate

the expected numbers of cases, and obtain the observed-to-expected ratios (O/Es). As in the previous study, 90% confidence intervals (CIs) rather than the more common 95% CIs were determined.

The authors examined the O/Es and CIs for spontaneous abortion in two of the six broad occupational categories: "managerial" (which included computer programmers) and "clerical", and for "other", comprising the four categories with presumed uncommon VDU use (health, sales, services, manufacturing). They tabulated the data for each category in terms of VDU usage for 0, <15, and ≥15 hours per week. For the prior pregnancies, none of the O/Es significantly exceeded 1.00. For the current pregnancies, the only O/E significantly higher than 1.00 was for the clerical sector with ≥15 hours of usage per week: O/E = 1.26, 90% CI: 1.10-1.44. It is noteworthy, however, that the corresponding result for "managerial" (including computer programmers) with ≥15 hours of usage per week was not significant: O/E = 1.00, 90% CI: 0.69-1.42.

The authors then examined 60 occupational populations for VDU usage for 15 or more hours per week and determined the subpopulation in each occupation for such usage in terms of the following percentage intervals: 0, <2, 2-5, 5-10, 10-20, 20-40, 40-60, and ≥60. For 21 of the 60 occupations (which had 19.5% of the total number of pregnancies), none of the women had used VDUs for 15 or more hours per week, those in 10 occupations (15.5% of the pregnancies) consisted of <2% of those subpopulations with such usage, the women in 6 occupations (9.5% of the pregnancies) comprised 2%-5% of subpopulations with such usage, those in 12 occupations (27.5% of the pregnancies) comprised 5%-10% of subpopulations with such usage, and the women in each of the remaining 17 occupations (28.0% of the pregnancies) each comprised ≤5% of subpopulations with such usage. In those subpopulation intervals, the O/Es for spontaneous abortions in the current-pregnancy cases respectively were: 0.99, 0.95, 0.97, 1.01, 1.05, 1.06, 1.07, and 0.96, with an overall value of 1.00 and no trend evident with increasing percentage of VDU-usage for 15 or more hours per week. The estimated relative risk for the use of VDUs was 1.06, 90% CI: 0.8-1.4.

Regarding the O/Es for stillbirths, no variation other than by chance was found. The O/Es for preterm births (<37 weeks) and for low birthweights (≤2500 g) all had 90% CIs that spanned 1.00 (nonsignificant).

The authors presented a tabular summary of their results for all adverse outcomes, and noted that only for spontaneous abortion in current pregnancies was there any indication of possible higher risk from VDU usage. However, they discounted that finding with the suspicion that it was due to recall bias. One can add that in the few instances where specific results were deemed significant because the O/Es exceeded unity and the 90% CI ranges did not span unity, use of 95% CIs most likely would have rendered those results nonsignificant as well.

In the first of a two-part study, Ericson and Källén (1986a) examined the Swedish Medical Birth Registry of computerized records of all births after 1 January 1973 and the Swedish Registry of Congenital Malformations. Using each woman's personal identification number, the authors derived occupational information by linking records of the Medical Birth Registry for 1976 and 1977 with census data for 1975, and the records of the Medical Birth Registry for 1980 and 1981 with census data for 1980, thereby adding the occupational code for each woman to the Medical Birth Registry for the two 2-year periods. Each

record included a summary of information retrieved from the maternal health center, the delivery unit, and the pediatric investigation of the neonate. From the occupational data, women of similar social strata could be grouped, but with different probabilities of exposure to VDTs.

By the methods above, the three groups of women below were selected by their presumed probability of working with VDTs. All of the women were white-collar workers of a similar social stratum.

<u>Group 1 (High)</u>: This group consisted of three subgroups with high probability of VDT usage in 1980-1981: those for computer operators (occupation code 291), travel-agency clerks (293), and social-insurance clerks (297). Only the first subgroup was thought to have had marked exposure in 1976-1977.

<u>Group 2 (Medium)</u>: This group was thought to have had substantial VDT usage, but not as much as Group 1. It consisted of those with the occupation code for secretary or typist (290) combined with the "branch of industry code for insurance company (8200)".

<u>Group 3 (Low)</u>: This group was thought to work only rarely with VDTs. It consisted of the three subgroups with occupation codes for postoffice assistants (651), bank cashiers (203), and librarians and women working in museums (093).

The endpoints studied were stillbirths, early neonatal deaths (age < 7 days), birthweights, and the presence of specific malformations defined as "significant" from the ICD codes and excluding minor and variably registrable conditions. The malformation diagnoses from the records of the Medical Birth Registry were analyzed in detail, and the information was supplemented with data from the Registry of Congenital Malformations.

Information on hospitalizations for spontaneous abortion was obtained by the use of the Inpatient Registry for Somatic Care. This registry covered about 80% of the women in Sweden, and included discharge diagnoses for all patients treated in somatic wards. (Although not mentioned by the authors, presumably not readily identifiable were women who had spontaneous abortions without being hospitalized.)

The results for the periods 1976-1977 and 1980-1981, as summarized by the authors in their Table IV, are shown in Table 26 (adapted therefrom). The expected numbers were estimated from national figures after standardization for maternal age and parity, and for delivery unit distribution.

TABLE 26: OBSERVED (O) AND EXPECTED (E) PREGNANCY OUTCOMES FOR LOW, MEDIUM, AND HIGH EXPOSURE GROUPS FROM OCCUPATIONAL USAGE OF VIDEO DISPLAY UNITS FOR THE PERIODS 1976-1977 AND 1980-1981

[Ericson and Källén (1986a)]

	EXPOSURE GROUP					
	LOW		MEDIUM		HIGH	
Period	1976-1977	1980-1981	1976-1977	1980-1981	1976-1977	1980-1981
Perinatal deaths						
O	17	9	15	8	19	16
E	18.2	13.0	14.0	5.5	19.9	20.1
O/E	0.9	0.7	1.1	1.5	1.0	0.8
95% CI	0.5-1.5	0.3-1.3	0.6-1.8	0.6-2.9	0.6-1.5	0.5-1.3
Significant malform.						
O	22	26	14	11	14	53
E	28.9	27.5	21.9	11.7	29.2	42.8
O/E	0.8	0.9	0.6	0.9	0.5	1.2
95% CI	0.5-1.2	0.6-1.4	0.3-1.1	0.5-1.7	0.3-0.8	0.9-1.6
Birth weight <1500 g						
O	9	12	14	10	10	21
E	11.5	10.4	9.1	4.5	12.9	16.4
O/E	0.8	1.5	1.5	2.2	0.8	1.3
95% CI	0.4-1.5	0.6-2.0	0.8-2.6	1.1-4.4	0.4-1.5	0.8-2.0
Birth weight <2500 g						
O	69	58	86	38	99	109
E	74.9	70.4	59.0	30.6	84.1	110.9
O/E	0.9	0.8	1.5	1.2	1.2	1.0
95% CI	0.7-1.2	0.6-1.1	1.2-1.8	0.9-1.7	1.0-1.4	0.8-1.2
Spontaneous abortions						
O	--	137	--	56	--	219
E		146.8		56.1		209.1
O/E		0.9		1.0		1.1
95% CI		0.8-1.1		0.8-1.3		0.9-1.2

It is seen that the only statistically significant results [O/Es 1.0 or larger, with 95% CI ranges above 1.0] are for birth weights <1500 g in the 1980-1981 medium-exposure group (O/E = 2.2, CI: 1.1-4.4), birth weights <2500 g in the 1976-1977 medium-exposure group (O/E = 1.5, CI: 1.2-1.8), and birth weights <2500 g in the 1976-1977 high-exposure group (O/E = 1.2, CI: 1.0-1.4). As noted by the authors, comparisons of the two time periods within each group suggest slight trends, both upward and downward, with greater VDT usage in the later time period. They remarked: "The absence of registrable effects could be due to a strong dilution of the material--that only a small proportion of the women actually worked with video screen equipment during pregnancy in the High group," which led them to do the case-control study discussed below.

In their case-control study, Ericson and Källén (1986b) selected cases from the Low, Medium, and High cohorts of women for the period 1980-1981 in previous study who, in all of their pregnancies, had: identified spontaneous abortions; stillbirths and infants dead after birth; infants with severe malformations, selected from the Medical Birth Registry and the Registry of Congenital Malformations; or infants with birthweight <1500 g. Two controls were sought for each case when possible: women in the same cohort as the case, taken from the same birth year and similar maternal age group, who did not fulfill the criteria above. Ultimately, 522 cases and 1,032 controls were selected.

The authors found that some women could enter the study more than once: either as a case twice (for two different criteria or twice for the same criterion) or once each as a case and control. To use only one questionnaire for each woman, the selection process was as follows: If the outcomes for a woman were a spontaneous abortion and a birth defect, the latter was kept; if both cases were spontaneous abortions or birth defects, the first occurring outcome was kept; a woman fulfilling both the case and control criteria was entered as a case. Questionnaires were mailed to those selected. Included were queries about the nature and duration of outside work during pregnancy; specifically whether the work involved contact with various chemicals, stress, heavy lifting, use of video screens, and smoking and/or working in smoky rooms. The overall response rate was 93%.

The authors presented a table showing that women who had reported some contact with chemicals comprised only 5.8% of those who responded to that query. Another table indicated that 41.2% of the women reported experiencing stress often or always when working. The reported stress rate was higher among women who had an infant with a birth defect (52.5%) or a spontaneous abortion (45.7%) than among the control women (38.4%). The overall O/E was 1.2 (with no CI given).

Heavy lifting was reported by respectively only 3.0% and 0.5% of those in the High and Medium groups, but by 20.9% of those in the Low group, the latter in part by postoffice workers who handled mail packages. Those who reported heavy lifting and had an infant with a birth defect or a spontaneous abortion respectively comprised 11.8% and 9.6%, as compared with 7.5% of the controls, yielding an overall O/E of 1.4 (with no CI given).

Working in smoky rooms was reported by 28.8%, 14.9%, and 9.6% of those in the High, Medium, and Low groups. The overall O/E was 1.0. Of those who worked in smoky rooms, 25.% were smokers and 15.8% were nonsmokers. Excluding those who reported stopping smoking (presumably while pregnant), all smokers comprised 31.1% of the women: 35.4% in the High group, 28.2% in the Medium group, and 25.1% in the Low group. Of those who had an infant with a birth defect or a spontaneous abortion, 22.5% and 34.4% respectively were smokers, as compared with 30.9% of the controls, yielding an overall O/E of 1.0.

A summary of the results on pregnancy outcome versus VDT usage is shown in Table 27 (adapted from Table VIII of the paper).

TABLE 27: CASE-CONTROL ANALYSIS OF EFFECT OF VIDEO SCREEN USAGE ON PREGNANCY OUTCOMES FOR THE PERIOD 1980-1981

[Ericson and Källén (1986b)]

OUTCOME	EXPOSURE*	O/E	95% CI
Spontaneous abortion	Any	1.1	0.8-1.4
	Early	1.1	0.9-1.4
	> 10 hr/wk	1.2	0.9-1.7
	> 20 hr/wk	1.2	0.9-1.7
Birth defect	Any	1.6	1.0-2.4
	Early	1.7	1.1-2.6
	> 10 hr/wk	2.0	1.2-3.2
	> 20 hr/wk	2.3	1.4-3.9
All cases	Any	1.2	0.9-1.5
	Early	1.2	1.0-1.5
	> 10 hr/wk	1.4	1.1-1.8
	> 20 hr/wk	1.4	1.1-2.0

*"Any": Any video screen work irrespective of time of pregnancy.
"Early": video screen work in early pregnancy irrespective of weekly duration.
"> 10 or 20 hr/wk": Weekly video screen work during early pregnancy.

The results above indicate O/Es exceeding 1.0 for birth defects that were statistically significant, with a trend toward an increase in O/E with exposure-duration, but nonsignificant values for spontaneous abortion. The authors also presented a graph of O/E for spontaneous abortion versus <5, 5-9, 10-14, 15-19, and 20+ hours per week of video screen work. The five O/Es were about 0.7, 1.1, 0.9, 1.7, and 1.3, respectively (with no CIs shown), regarded by the authors as a tendency for a dose-related effect.

Overall, the authors remarked: "The effects are small, and therefore a number of alternative explanations must be considered before a causal relation is implied." They gave some specific data indicative of possible selective non-response rates and for recall bias in those who did respond. They also noted that data on induced abortions (absent in this study) would complicate such a study, e.g., specific pregnancies may be less acceptable (and perhaps aborted) by some more-skilled women, such as those performing computer work, than by other women. Regarding birth defects, they indicated that there was no specific pattern of defect type among infants of mothers who had worked 10 hours or more a week with video screens, compared with infants whose mothers had not done such work during early pregnancy, and suggested that the strong association between stress, smoking, and video screen work renders it very difficult to separate the effects, and that an attempt to do so for those who had worked 10 hours or more a week with video screens yielded a decrease in O/E to nonsignificance.

Goldhaber et al. (1988) noted that the findings of various studies done through about 1987 on possible effects of the electromagnetic fields from VDTs yielded equivocal findings, but that a consensus had been reached that neither ionizing nor nonionizing radiation from VDTs is likely to affect reproductive or other health outcomes. However, previous studies were of relatively small population sizes and contained possible biasing factors, thus leading the authors to conduct their case-control study of pregnancy outcome.

Using data from the Kaiser Permanente Medical Care Program (KPMCP), the authors first attempted to identify all women reporting for pregnancy testing at three KPMCP obstretrics and gynecology clinics in the southern part of San Francisco Bay Area (Hayward, Santa Clara, Redwood City) from 15 September 1981 through 30 June 1982, a period during which the area had been sprayed with the pesticide malathion. Pregnancies totaling 9,654 were identified, and their outcomes were determined by computer linkages to KPMCP hospital discharge summaries of live births (6,441) or fetal loss (131) and to California birth certificates for live births other than in KPMCP hospitals (207). Manually reviewed also were clinic abortion logs and other clinic records for voluntary abortions (1,802), as were individual records for miscarriages and other fetal losses not requiring hospitalization (540) and for live births not found by hospital or birth-certificate searches (111).

Tabulated were 9,623 fetal outcomes in 9,564 pregnancies, of which 6,291 were normal births, 2,941 births had abnormalities of various types, and 391 unknown outcomes. Individual medical records were reviewed for confirmation of all adverse and unknown outcomes, the latter mostly consisting of women who had terminated their membership in the KPMCP during pregnancy. Analysis of all pregnancies in the cohort for at least three days after the pregnancy diagnosis showed an incidence of about 12% for spontaneous abortion from the fifth week of gestation, within the expected range for cohort studies. In two of the three KPMCP hospitals (where about 76% of the births had occurred), the birth-defect rates were similar to the 1983 rate for San Francisco Bay Area, but the third KPMCP hospital, which historically had underreported birth defects in its discharge summaries, yielded a rate substantially lower than the area-wide rate.

Starting in July 1984, questionnaires were sent, in three mailing waves about three weeks apart, to cohort women over 17 years of age with singleton pregnancies, including all those who had miscarriages less than 28 weeks since the last menstrual period (556); all those with birth defects reportable by the standards of the California Birth Defects Monitoring Program (156); and a 20% sample (1,123) of the women with normal births, selected from every fifth live birth with no birth defects, or births with growth retardation less than two standard deviations below the mean for gestation age, or no infant deaths within 28 days.

Those who had not responded were solicited by telephone. The final response rates were 82.7% for miscarriages, 87.8% for reportable birth defects, and 87.8% for the controls. The refusal rates were less than 5% for all outcomes, and the majority of the nonresponses were due to untraceability. The information collected included residence during the period of pesticide spraying, consumption of tap and bottled water, caffeine, alcohol, and cigarettes; and pesticide exposure. Information was also collected on work done during each pregnancy trimester, and occupation and industry codes were assigned in accordance with the 1980 classifications of the Census Bureau. All women were requested to state the approximate numbers of hours per week they had spent using a VDT during each trimester. The women who had worked outside the home during pregnancy were then grouped into those who reported no VDT use, low VDT use (<5 hours a week), medium VDT use (5-20 hours a week), and high VDT use (>20 hours a week) during the first trimester of pregnancy.

The relative risk of each anomalous pregnancy outcome was estimated by calculating the ratio of the number of cases of each anomalous outcome to the number of live births in each VDT-use group and dividing that ratio by the corresponding ratio in the no-VDT-use group, with the result called the odds ratio (OR) for that outcome. Logistic regression was used to adjust for effects of covariates known or suspected to be related to pregnancy outcome: maternal age, history of previous abnormal pregnancies, race, education, smoking, alcohol use, occupation, and either gestational age at pregnancy diagnosis (for analysis of miscarriage risk) or hospital of delivery (for analysis of birth defect risk). Excluded were the second pregnancies of 10 women who had been pregnant twice during the study period, and 20 women for whom covariant data were incomplete. Most of the covariates were treated as dichotomous or linear, but two were transformed because of curvilinear relations with miscarriage risk. The adjusted ORs and 95% CIs for miscarriage and birth defects are shown in Table 28 (adapted from Table IV of the paper).

TABLE 28: ADJUSTED ODDS RATIOS FOR MISCARRIAGES AND BIRTH DEFECTS AMONG WORKING WOMEN FROM REPORTED VDT USE DURING FIRST TRIMESTER OF PREGNANCY

[Goldhaber et al. (1988)]

VDT Use	Miscarriages	Live births	OR	95% CI
		MISCARRIAGE		
None	240	510	1.0	---
Low	29	77	0.9	0.6-1.4
Medium	34	71	1.0	0.6-1.6
High	52	65	1.8	1.2-2.8
Total	355	723	---	---
		BIRTH DEFECTS		
None	65	510	1.0	---
Low	8	77	0.9	0.4-1.9
Medium	12	71	1.4	0.7-2.7
High	12	65	1.4	0.7-2.9
Total	97	723	---	---

Overall, the authors indicated that the estimated OR associated with any VDT use versus none was 1.2 (95% CI: 0.9-1.6) for miscarriage and 1.2 (95% CI: 0.7-1.9) for birth defects, both statistically nonsignificant. With regard to VDT usage levels, the ORs above for birth defects were all nonsignificant, but was significant (OR = 1.8; CI: 1.2-2.8) for miscarriage in those who reported high VDT use. The ORs for miscarriage were also tabulated by the occupational categories: "Managers/professionals", "Technical/sales", "Administrative support/clerical", and "Service/blue-collar". The only significant result was for the high-VDT-use women in the Administrative support/clerical category (an OR of 2.4 with a footnote that the 95% CI did not include 1).

Odds ratios were presented in which the reference group consisted of the nonworking women (99 miscarriages and 253 live births, excluding those with VDT use at home) instead of the working women with no VDT use. One of the two statistically significant results was for miscarriages in the high-VDT-use women of the Administrative support/clerical category (an OR of 2.0 with a footnote that the 95% CI did not include 1). The other significant result was

for miscarriages in the working women with no VDT use in the Technical/sales category relative to the nonworking women in that category (an OR of 1.8 with the same footnote).

The authors remarked that the latter result above is suggestive of an occupational effect not related to VDT use. They also noted that an unusually low risk was observed for moderate VDT use by Managers/professionals, and that in all occupational categories except Administrative support/clerical, the numbers of high VDT users were too small to draw reliable conclusions. They regarded their findings as suggestive that high usage of VDTs may increase the risk of miscarriages, but considered ergonomic and other nonexposure factors as possible contributors to the positive findings.

Bryant and Love (1989) did a case-control study in Calgary, Canada, of women in hospitals with a diagnosis of spontaneous abortion, defined as the unintentional cessation of pregnancy before 20 weeks of gestation. The women were interviewed while in hospital, to prevent possible selection bias were they allowed to return to their normal activities before being interviewed.

One of two control groups consisted of women selected from available local prenatal class lists or from the patient lists of cooperating family physicians and obstetricians with admitting privileges in those hospitals. Those controls were interviewed before 25 weeks of gestation, with recognition that they were most motivated toward early prenatal care. The other control women were recruited from those in the postpartum units of the participating hospitals following delivery of a normal infant (defined as liveborn with birthweight 2500 g or more, a stated gestational age of 37 to 42 weeks, no noted defects, and a hospital stay not longer than 7 days and not requiring intensive care). Both groups were post-matched to the cases by age at last menstrual period (LMP) within the same 5-year interval (15-19, 20-24, etc.), parity (0, 1, or 2+) and intended delivery hospital. Matching was successful for 333 cases with postnatal controls and 314 cases with prenatal controls.

Special edge-coded questionnaires were developed for the study. The interviewers had previous health-care training and specific training for the project. They edge-coded the data collected onto the questionnaires, except for complex codes, such as for occupation; such coding was done by research assistant and/or project coordinator. The data were analyzed statistically by logistic regression. The overall response rates were 91.3% for the cases, 81.4% for the prenatal controls, and 87.5% for the postnatal controls. The majority of the cases were first-trimester abortions.

The authors characterized VDT usage by case and control women as at any time between: 3 months pre-LMP to 4 months post-LMP, 3 months pre-LMP to LMP, LMP to 2 months post-LMP, or 2 months post-LMP to 4 months post-LMP. The ORs and 95% CIs for each such VDT usage periods relative to no VDT usage indicated no significant differences between cases and either of the control groups. Further quantification of VDT usage revealed that fully a third of the women who reported such usage had extremely low levels of "exposure", such as at home (casual use) and/or to video games at four or more feet from the screen. An analysis in which those women were reclassified as "unexposed" also yielded no significant differences between cases and controls. For the cases and controls who reported non-casual VDT usage, their usage was segmented into <2, 2-10, 11-20, and >21 hours a week. The highest OR was for the cases relative

the postnatal controls, with usage for less than 2 hours a week: 1.49 and a 95% CI of 0.89-2.49. Also, the findings for VDT use remained negative when income, education, cigarette use, and alcohol use were considered in the logistic regression analysis.

The authors presented an interesting discussion on the possible effects of recall bias, suggesting that cases are more likely to report past exposures than controls [citing Bracken (1984)] and that data for controls are likely to reflect under-reporting. They specifically noted that such under-reporting may have occurred among the casual-user postnatal controls in their study.

Schnorr et al. (1991) studied a population of pregnant women consisting of directory-assistance and general telephone operators at two companies in eight southeastern states. The directory-assistance operators used VDTs, whereas the general telephone operators used units containing lght-emitting diodes or neon glow tubes for displaying telephone numbers. Typically, each group worked 8½-hour days that included 1 hour for lunch and two 15-minute breaks. The operators sat in front of the equipment during the entire work time and the time between calls was usually less than one second. The authors remarked that the primary difference between the groups was the presence or absence of the VDTs. Eligibility requirements for the study were: age 18 to 33 years (born after 30 June 1953) and married at any time during the study period; full employment at any time between 1 January 1983 and 1 August 1986.

The study was described to both interviewers and potential participants as a study of pregnancy outcomes among office workers. Sought by telephone interviews were lifetime reproductive histories, information on consumption of alcohol and cigarettes, use of medications and other treatments, and medical conditions.

Only pregnancies that met the following criteria were selected:

Pregnancies that resulted in a live birth, stillbirth (fetal loss after 28 weeks of gestation), or spontaneous abortion (fetal loss at 28 weeks of gestation or earlier).

Employment for at least one day during the first 28 weeks of pregnancy.

End of pregnancy between 1 January 1983 and 31 December 1986 for spontaneous abortions or between 1 May 1983 and 31 December 1986 for live births and stillbirths. (The authors remarked that introduction of VDTs at general-operator workstations had begun after December 1986.)

To identify possible recall differences on pregnancy outcome, the state vital record on each live birth reported during the study period was obtained, and the number of previous pregnancy ends shown on the birth certificate was compared with the number reported in the interview. In addition, each woman was asked if she had consulted a physician about a spontaneous abortion, and the latter data were analyzed separately.

The authors defined VDT use in two ways. First, VDT use was treated as as a dichotomous (yes or no) variable: A pregnancy was classified as exposed if the woman had worked as a directory-assistance operator at any time during the first trimester of pregnancy (13 weeks), or as unexposed if the woman had

worked solely as a general operator during the first trimester. Second, to assess for a possible dose-response relation, weekly payroll records were used to calculate the hours of VDT use during each study pregnancy.

For exposed pregnancies, the authors formed two indexes of continuous exposure: In one, the hours of VDT use per week were calculated by dividing the number of hours of VDT use during the first trimester (remarked by the authors as the period of greatest risk of spontaneous abortion) by the number of hours of pregnancy during the first trimester, and multiplying that ratio by 168 hours per week. The second index was the number of hours of VDT use during the first 28 weeks of gestation (remarked as the entire period of risk for spontaneous abortion in their study). The authors defined the rate of spontaneous abortion as the ratio of the number of spontaneous abortions to the sum of spontaneous abortions and live births.

Multiple logistic regression analysis was used to calculate the effect of VDT use on the incidence of spontaneous abortion and to control for the effects of other variables. Separate analyses were done for early and late spontaneous abortions (≤8 weeks and 9-28 weeks of gestation). Other analyses done was one that included stillbirths and excluded spontaneous abortions not reported to a physician, and another to address the fact that the outcomes of seveal pregnancies in the same woman are not independent events.

The electromagnetic fields were measured for 6 randomly selected VDTs at 8 of 50 directory-assistant offices for a total of 48 VDTs [24 each of IBM model 4978 and Computer Controls, Inc. (CCI) model 4500]. For comparison, the fields emitted by 24 each of randomly selected light-emitting diodes (LEDs) and neon glow tubes (NGTs) at two sites (with all of the VDTs in the vicinity disabled). The X-ray emissions were measured by slowly passing a Stoms meter over every accessible surface of the VDT and non-VDT units. The electric and magnetic fields in the VLF range (3 to 30 kHz) and ELF range (30 to 300 Hz) were measured (with Holaday Industries models HI 3600-01 and HI 3600-02) at 30 cm from each side of the unit with the operator absent, and at the operator's face, chest, and abdomen while seated at the unit. In addition, more detailed measurements were made at one of the six units at each site, including the spatial variation of field strengths between 10 and 100 cm from the screen and the time-rate-of-change of magnetic flux density in the VLF range.

The X-ray emissions from the VDT and non-VDT units did not differ from the background levels. The VLF and ELf measurements are shown in Table 29 (adapted from Table 5 of the paper). The authors noted that the CCI and IBM VDTs emitted ELF energy respectively at 45 Hz and 60 Hz, and that both emitted VLF energy in the 15-kHz range. The time-rate-of-change of VLF magnetic flux density ranged from 9.0 to 38.0 mT/s. The LEDs and NGTs did not emit VLF energy above background levels.

TABLE 29: VLF AND ELF EMISSIONS FROM VDT AND NON-VDT UNITS
[Schnorr et al. (1991)]

GEOMETRIC MEAN LEVELS (STANDARD DEVIATIONS)

Frontal Emissions (operator absent)

	VLF		ELF	
	E-field (V/m)	H-field (mA/m)	E-field (V/m)	H-field (mA/m)
VDT				
CCI	4.2 (1.54)	98.9 (2.61)	1.9 (1.63)	313.6 (1.22)
IBM	3.3 (2.07)	22.1 (4.68)	1.8 (1.93)	236.1 (2.14)
NON-VDT				
LED	0.1 (1.16)	1.6 (1.01)	0.4 (1.10)	72.3 (1.68)
NGT	0.1 (2.05)	1.4 (1.04)	0.5 (1.40)	30.3 (1.72)

Abdominal Exposure (operator present)

	VLF		ELF	
	E-field (V/m)	H-field (mA/m)	E-field (V/m)	H-field (mA/m)
VDT				
CCI	0.5 (1.68)	17.4 (1.74)	0.8 (3.61)	62.3 (1.59)
IBM	0.1 (1.71)	4.0 (1.85)	0.4 (1.70)	57.7 (2.12)
NON-VDT				
LED	0.1 (1.35)	2.0 (1.15)	0.4 (1.18)	62.4 (2.79)
NGT	0.2 (1.64)	1.6 (1.00)	0.4 (1.92)	32.4 (2.01)

The net response rate in the interviews was 76.6% (4246 women), with similar participation rates by the two groups. Of those 4246 women, 2430 were married during the study period and 730 of them had one or more eligible pregnancies, yielding a total of 882 pregnancies, including 16 with twins. The percentages of live births, spontaneous abortions, and stillbirths were comparable for directory-assistance and general operators.

The crude rates of spontaneous abortions were 14.8% and 15.9% for VDT-exposed pregnancies for unexposed pregnancies, respectively. The spontaneous-abortion rates for those who had 1 to 25 hours and for those who had more than 25 hours of VDT use per week during the first trimester did not significantly differ from the rates for those with no VDT use. Also, the multiple logistic-regression model showed no association between VDT use in the first trimester and spontaneous abortion (OR=0.93; 95% CI: 0.63-1.38). Other factors found to be associated with altered risk of spontaneous abortion were: a history of spontaneous abortion, consumption of more than 8 alcoholic drinks per month, smoking more than 20 cigarettes a day, and the presence of a thyroid disorder.

2.6.1 SUMMARY ON RFR-EXPOSURE FROM VIDEO DISPLAY TERMINALS

The findings of the various studies on a possible association between exposure of pregnant women to the RFR from video display terminals (VDTs) and miscarriages or birth defects are summarized in Table 30 (A, B, C, and D).

Authors	Effects Sought or Examined	Exposure Modality	Effects Reported	Notes & Comments
Weiss and Petersen (1979) Petersen et al. (1980)	Electromagnetic emissions from eight representative VDTs at Bell Labs.	Frequency bands: 10 kHz-18 GHz, 350-600 nm (visible & UV), leakage of X-rays.	With 2 exceptions, measurable RFR levels occurred only at frequencies up to about 150 MHz; small signals of a few hundred MHz for the exceptions. For all units, the total RMS electric-field strengths were well below the most stringent exposure standard in the world. UV measurements at approximate normal viewing distance were well below those recommended in NIOSH (1972)*. In the 11 CRT types examined for X-ray leakage, only 1 model showed levels above the background (but less than the highest level allowable from TV receivers). Repair of a faulty high voltage power supply corrected the problem.	The RF/microwave results were tabulated; each table included the total RMS electric-field strength for each unit. *NIOSH (1972): "Criteria for a recommended standard for occupational exposure to ultraviolet radiation"
Stuchly et al. (1983)	Electric-field levels emitted by 86 VDTs (57 models) from 25 firms.	Measurements were made in the range 15-150 kHz (stray fields from fly-back transformers) at the operator position, at the keyboard, and at the locations of maximum level at the screen surface, top, sides, and back of the various VDT models.	The levels at the operator position were less than 1 V/m for 37 models and ranged from 1 to 5 V/m for the other 20 models. The highest level at any keyboard was 7 V/m; the levels exceeded 5 V/m for only 4 models. Also, the keyboard levels were below 1 V/m for 33 models and between 1 and 5 V/m for the other 20 models. The highest levels at the VDT surfaces were: below 5 V/m for 10 models, in the ranges 5-60 V/m for 22 models, 60-200 V/m for 10 models, and exceeded 200 V/m for 15 models. For the 3 models that had maxima at the screen, the level at 10 cm from the screen dropped to less than 70 V/m.	The authors also tabulated the spatial-average and maximum SARs in a prolate spheroidal human model exposed to plane waves at 10, 20, 50, 100, and 200 kHz at 1 V/m, with the long axis parallel to the field. The highest spatial-average and maximum SARs were 0.000017 and 0.005 W/kg, both at 200 kHz, with the maxima at the surface of the model facing the source.
Nurminen and Kurppa (1988) Kurppa et al. (1985).	Pregnancy outcomes of Finnish women in occupations involving use of VDTs during pregnancy, based on occupational titles.	Average exposure times per workday were grouped as follows: 4 hours or more (33 women), less than 4 hours but at least 1 hour (10 women), and less than 1 hour (21 women).	Of 239 mothers with possible VDT usage, 8.4% had symptoms of threatened abortion as compared with 9.8% of 805 mothers in non-office work (nonsignificant). Also not significant was the difference in percentages of those who had bleeding or pain during pregnancy. The mothers in office and non-office work had similar proportions of preterm, term, and prolonged pregnancies, and there were no significant differences in neonate birth weights. The authors concluded that they had found no indication of work-related reproductive problems in offices or in VDT work in particular.	Case and control mothers were interviewed about their work conditions and their various occupational and leisure-time activities, but were not asked specific questions about VDT work. Instead, occupational titles were used to recognize those in office work with possible VDT usage. The authors recognized that the smallness of the VDT group precluded more detailed analyses for possible differences between groups.

TABLE 30A: RFR FROM VIDEO DISPLAY TERMINALS AND PREGNANCY OUTCOMES

Authors	Effects Sought or Examined	Exposure Modality	Effects Reported	Notes & Comments
McDonald et al. (1986)	Pregnancy outcomes after delivery or spontaneous abortion by 56,012 women in 11 Montreal hospitals who occupationally used VDUs [VDTs].	No field exposure levels were given, but those with VDU usage for at least 15 hours per week were regarded as exposed.	In a total of 8,805 current pregnancies comprising both users and nonusers of VDUs, there were birth defects in 311 pregnancies (3.5%); of 3,257 VDU users in the 8,805 pregnancies, there were birth defects in 108 pregnancies (3.3%). Similar results were shown for previous pregnancies. The authors concluded that in VDU users, there was no excess in the overall rate of defects or in any of the specific defect categories. Odds ratios for spontaneous abortions in current pregnancies versus the ranges of VDU usage (none, 1-6, 7-29, or ≥30 hours a week) were 0.89, 1.24, 1.25, and 1.12, but with a 90% confidence interval (CI) that spanned 1.00 for the greatest usage (≥30 hours a week), rendering that odds ratio nonsignificant. In general, the authors found no association between VDU usage and the incidence of spontaneous abortion. Unclear is why they used 90% CIs instead of 95% CIs.	Of the 56,012 then pregnant women (approximately 90% of all Montreal births), 25,418 were in paid employment for 30 or more hours per week at the start of pregnancy; of 48,608 women with prior pregnancies, 22,697 were similarly working. The authors remarked that one possible confounding factor was the rapid rise in VDU use during the study period (1982-1984), and therefore they used separate models for current and previous pregnancies; logistic regression was used to estimate the contributions of such possibly confounding factors as maternal age, number of prior pregnancies, and smoking on abortion risk.
McDonald et al. (1988)	The authors added a 29 other cases to those considered in McDonald et al. (1986), and they analyzed incidences of stillbirth and low birthweight as well as of abortion and birth defects.	VDU uses during prior and current pregnancies were shown as: 0, <15, and ≥15 hours per week for 6 broad occupational categories.	None of the observed to expected ratios (O/Es) for spontaneous abortion in the previous pregnancies significantly exceeded 1.00. For current pregnancies, the only O/E that significantly exceeded 1.00 was in the clerical sector with ≥15 hours of usage per week: O/E=1.26, 90% CI: 1.10-1.44. Noteworthy, however, is that for the "managerial" occupational category, in which computer programmers were included, the O/E was 1.00 with a 90% CI of 0.69-1.42. Regarding the O/Es for stillbirths, no variation other than by chance was found, and the O/Es for preterm births (<37 weeks) and low birthweights (≤2500 g) all had 90% CIs that spanned 1.00 (nonsignificant).	In a summary of all of the adverse outcomes, the authors indicated that for spontaneous abortion in the (then) current pregnancies only was there any suggestion of possible higher risk from VDU usage, but they discounted that finding with the suspicion that it was due to recall bias. One can add that in the few results deemed significant, the use of 95% instead of CIs 90% probably would have rendered those results nonsignificant also.

TABLE 30B: RFR FROM VIDEO DISPLAY TERMINALS AND PREGNANCY OUTCOMES (CONTINUED)

Authors	Effects Sought or Examined	Exposure Modality	Effects Reported	Notes & Comments
Ericson and Källén (1986a)	Effects of VDT usage on stillbirths, early neonatal deaths, birthweights, and malformations in Sweden during 1976-1977 and 1980-1981.	Usage of VDTs in various occupations was characterized as high, medium, or low.	The only statistically significant results were for birth weights <1500 g in the 1980-1981 medium-exposure group (O/E = 2.2, CI: 1.1-4.4), birth weights <2500 g in the 1976-1977 medium-exposure group (O/E = 1.5, CI: 1.2-1.8), and birth weights <2500 g in the 1976-1977 high-exposure group (O/E = 1.2, CI: 1.0-1.4). The authors noted that comparisons for the two time periods within each group suggested slight trends, both upward and downward, with greater VDT usage in the later time period.	The authors remarked: "The absence of registrable effects could be due to a strong dilution of the material--that only a small proportion of the women actually worked with video screen equipment during pregnancy in the High group." This led them to do a case-control study [Ericson and Källén (1986b)].
Ericson and Källén (1986b)	Effects of VDT usage in 522 cases selected from the previous study for the period 1980-1981 versus 1,032 controls.	VDT usage was high, medium, or low as in the prior study. Cases were selected from women who had had spontaneous abortions, still-births and infants dead after birth, infants with severe malformations or with birthweights <1500 g.	Significant O/Es (exceeding 1.00, with 95% CIs above 1.00) were shown for birth defects, with a trend toward an increase in O/E with exposure duration. The O/Es for abortion were not significant, but the authors displayed a graph of O/E for that endpoint versus <5, 5-9, 10-14, 15-19, and 20+ hours per week of VDT use. The five O/Es were about 0.7, 1.1, 0.9, 1.7, and 1.3 (with no 95% CIs given), regarded by the authors as a tendency for a dose-related effect.	The authors remarked that the effects were small, and they suggested several alternative explanations, with specific data indicative of possible selective non-response rates and for recall bias in those who did respond. They saw no specific pattern of birth-defect type among the infants of mothers with the most VDT use. They suggested that the strong association between stress, smoking, and VDT use rendered it very difficult to separate the effects, and that an attempt to do so for those who had high VDT use yielded a nonsignificant O/E.
Goldhaber et al. (1988)	Sought for women in the Kaiser Permanente Medical Care Program (KPMCP) who were pregnant during the period 15 September 1981 through 30 June 1982 was a possible association between pregnancy outcome and VDT use.	Data were collected on work done during pregnancy and on VDT use, and the women were assigned occupation codes. VDT usage during the first trimester of pregnancy was subdivided into none, low (<5 hours a week), medium (5-20 hours a week), and high (>20 hours a week).	Tabulated were 9,623 fetal outcomes in 9,564 pregnancies, of which 65% were normal births, 31% of births had various types of anomalies, and 4% had unknown outcomes. The final response rates were 82.7% for miscarriages, 87.8% for birth defects, and 87.8% for controls (live births with no birth defects or growth retardation). The odds ratios (ORs) for the various anomalous outcomes were not significant except for miscarriages in those with high VDT use, but the overall miscarriage OR for any VDT use versus no VDT use was not significant.	Two ORs, in which the controls were nonworking women instead of working women with no VDT use, were significant for miscarriage: in administrative support/clerical women with high VDT use and for women in technical/sales with no VDT use, results that suggest an occupational effect unrelated to VDT use. The authors also suggested that although high VDT usage may raise the risk of miscarriages, ergonomic and other nonexposure factors may be contributors.

TABLE 30C: RFR FROM VIDEO DISPLAY TERMINALS AND PREGNANCY OUTCOMES (CONTINUED)

Authors	Effects Sought or Examined	Exposure Modality	Effects Reported	Notes & Comments
Bryant and Love (1989)	Sought was a possible association with VDT use by women in Calgary hospitals for spontaneous abortion. One set of controls were prenatal women before 25 weeks of gestation; the other controls were women in the same hospitals following birth of a normal infant. Using specific criteria, the authors matched 333 cases with postnatal controls and 314 cases with prenatal controls.	Cases and controls were said to have had VDT usage if they used VDTs at any time: between 3 months before their last menstrual period (LMP) and 4 months post-LMP, between 3 months pre-LMP and their LMP, between their LMP and 2 months post-LMP, or between 2 months post-LMP and 4 months post-LMP.	The ORs and 95% CIs for each such VDT usage period relative to no VDT usage indicated no significant differences between cases and either of the control groups. Further quantification of VDT usage revealed that fully a third of those who reported such VDT usage had extremely low levels of "exposure", such as at home (casual use) and/or to video games at four or more feet from the screen. An analysis in which those women were reclassified as "unexposed" also yielded no significant differences between the cases and controls. For the cases and controls who reported non-casual VDT usage, their usage was segmented into <2, 2-10, 11-20, and >21 hours a week. The highest OR was for the cases, relative to postnatal controls, with usage for less than 2 hours a week: 1.49 and a 95% CI of 0.89-2.49 (not significant). Also, the findings for VDT usage remained negative when income, education, cigarette use, and alcohol use were considered.	The authors presented an interesting discussion on the possible effects of recall bias, suggesting that cases are more likely to report past exposures than controls and that the data for controls are likely to reflect usage under-reporting. The authors noted specifically that such under-reporting may have occurred among the casual-user postnatal controls in their study.
Schnorr et al. (1991)	Pregnancy outcomes of directory-assistance operators (who used VDTs) versus general telephone operators (who used units that had light-emitting diodes or neon glow tubes for displaying telephone numbers).	Each group worked 8½-hour days (minus 1 hour for lunch and two 15-minute breaks). Electric and magnetic fields in the VLF (3 to 30 kHz) and ELF (30 to 300 Hz) ranges were measured from 24 VDTs each from two manufacturers, as were emissions of X-rays.	The crude rates of spontaneous abortions were respectively 14.8% and 15.9% for VDT-exposed pregnancies and unexposed pregnancies. The spontaneous-abortion rates for those who had 1 to 25 hours and for those who had more than 25 hours of VDT use per week during the first trimester did not significantly differ from the rates for those with no VDT use. In addition, a multiple logistic-regression model showed no association between VDT use in the first trimester of pregnancy and spontaneous abortion incidence (OR=0.93; 95% CI: 0.63-1.38). The authors also found no evidence of significant recall bias.	X-ray measurements showed no differences from background. A tabulation of VLF emissions at abdominal level (with the operators present) indicated means of 0.5 ± 1.68 (SD) V/m and 17.4 ± 1.74 mA/m for the VDTs from one manufacturer; the corresponding levels from the other manufacturer were lower. The mean ELF levels from the first type were 0.8 ± 3.61 V/m and 62.3 ± 1.59 mA/m, and were 57.7 ± 2.12 mA/m from the second type. The time-rate-of-change of VLF magnetic flux density ranged from 9.0 to 38.0 mT/s.

TABLE 30D: RFR FROM VIDEO DISPLAY TERMINALS AND PREGNANCY OUTCOMES (CONCLUDED)

2.6.2 CONCLUSIONS

Although several epidemiologic studies on possible adverse pregnancy outcomes from occupational usage of video display terminals (VDTs) yielded a few statistically significant odds ratios, the authors of those studies largely discounted those significant odds ratios as possibly due to factors other than RFR-exposure from VDTs, such as recall bias, occupational stress, ergonomics, and smoking. This was the case for Ericson and Källén (1986a, b), and Goldhaber et al. (1988). The studies that yielded negative findings were: Kurppa et al. (1985), Nurminen and Kurppa (1988), McDonald et al. (1986, 1987), Bryant and Love (1989), and Schnorr et al. (1991). As in epidemiologic studies on other topics, open to question are the validity of the assumptions underlying the statistical treatment of the data and the importance, relative to health, of presumably statistically significant odds ratios less than 2.

As scientific support for the absence of health effects from exposure to the RFR from VDTs, the levels from various VDTs determined in several studies were well below extant guidelines for maximum allowable exposure, suggesting that occupational exposure of pregnant women to the RFR from VDTs would not affect pregnancy outcome adversely. In particular, measurements by Weiss and Petersen (1979) and Petersen et al. (1980) of the electromagnetic fields in the frequency band 10 kHz to 18 GHz from the VDTs used by telephone operators yielded values far below the most stringent exposure standard in the world. Moreover, they found that the ultraviolet (UV) levels were well below the 1972 NIOSH criteria for occupational exposure to UV, and that the X-ray emissions from the cathode ray tubes of the VDTs were within background levels. Also, measurements by Stuchly et al. (1983) of the electric fields in the frequency range 15-150 kHz (from 86 VDTs manufactured by various firms) yielded levels not exceeding 5 V/m at the operator position, and maximum levels at the VDT surfaces ranged from less than 5 V/m for some units to greater than 200 V/m for others, but the corresponding levels at the operator position were less than 70 V/m.

It is noteworthy that the International Non-Ionizing Radiation Committee of the International Radiation Protection Association had issued a statement (IRPA, 1988b) in which possible health risks from visual display units (VDUs) were reviewed briefly, and which concluded that there is no health hazard from exposure to the electromagnetic fields from VDUs.

It is also important to note that in some studies at frequencies in the ELF range, the authors reported that magnetic fields from VDTs are hazardous, a subject not treated herein, because possible health effects of exposure to frequencies in the range 3 kHz to 300 GHz were the primary focus.

3 STUDIES OF HUMAN VOLUNTEERS--OTHER RFR EFFECTS

3.1 THE RFR-AUDITORY EFFECT

Humans near some types of pulsed radar transmitters can perceive single pulses or pulse trains of RFR as audible clicks without the use of electronic receptors. As discussed below, there is considerable experimental evidence supporting the hypothesis that an RFR pulse having a peak power density and duration within specific limits can produce a transient thermal gradient in the head large enough to generate a transient elastic wave at a boundary

between regions of dissimilar dielectric properties, and that this wave is transmitted by bone conduction to the middle ear, where it is then perceived by normal cochlear mechanisms as a click. Persons with impaired hearing are not able to hear such clicks, and animals with destroyed cochleas (inner ears) do not exhibit RFR-pulse-induced evoked responses in the brainstem. This phenomenon had attracted considerable interest because it was often cited as evidence that nonthermal effects can occur and because an initial hypothesis was that a possible mechanism for perception is direct stimulation of the central nervous system by RFR.

Frey (1961) exposed human volunteers to either 6-μs pulses of 1.3-GHz RFR at 244 pulses per second (pps) (0.0015 duty factor) or to 1-μs pulses of 3.0-GHz RFR at 400 pps (0.0004 duty factor). The mean threshold of average power density for RFR perception was about 0.4 mW/cm^2 at 1.3 GHz for eight subjects and 2 mW/cm^2 at 3.0 GHz for seven subjects. The corresponding peak power densities were about 270 and 5,000 mW/cm^2. (No variances or other statistical data were given.) The ambient noise levels were respectively about 70 and 80 dB, but earplugs decreased the noise by about 25-30 dB.

The subjects were unable to match the RFR sounds to audio sine waves. With white noise controlled by a variable band-pass-filter, best match was obtained by removing all frequencies below about 5 kHz.

Four subjects with various degrees of hearing loss (for air-conducted and bone-conducted sound) were tested for perception of the 1.3-GHz RFR. Subject 1 with significant hearing loss of both kinds above about 2 kHz was unable to perceive the RFR sound at intensities 30 times above the threshold. Subject 2, who had bilateral severe air-conduction loss (about 50 dB) but moderate bone-conduction loss (about 20 dB), was able to perceive the RFR sound at about the threshold level. Subject 3, with tinnitus and bilateral hearing loss ranging from about 10 dB at 250 Hz to 70 dB at 8 kHz for air conduction, more severe loss for bone conduction, and who had been diagnosed as having neomycin-induced nerve deafness, was unable to perceive the RFR. Subject 4, who had normal bilateral air-conduction hearing to about 4 kHz but severe bilateral bone-conduction loss also could not perceive the pulses. The author concluded that for perception of RFR as sound, a person must be able to hear sound above about 5 kHz, but not necessarily by air conduction.

In another study, however, Frey (1962) found that some subjects who had an audiogram notch (significant hearing loss) around 5 kHz (and adequate hearing above and below 5 kHz) did not perceive RFR pulses as sound. In this study, the RFRs used were 425-MHz pulses of 125, 250, 500, 1,000, and 2,000 μs at 27 pps (respective duty factors of 0.0034, 0.0068, 0.0135, 0.027, and 0.054) and 2.5-μs pulses of 8.9-GHz RFR at 400 pps (duty factor 0.001). The ambient noise levels were 70-90 dB and the subjects wore Flent antinoise ear stopples, which diminished the ambient levels by about 20 dB from 100 Hz to 2 kHz and by about 35 dB at 10 kHz.

The average-power-density thresholds for perception of 125-, 250-, 500-, and 1000-μs pulses of 425-MHz RFR were respectively 1.0, 1.9, 3.2, and 7.1 mW/cm^2, and the corresponding peak power densities were 300, 280, 240, and 260 mW/cm^2 (again without statistical data). (The threshold for 2,000-μs pulses of 425-MHz RFR was not determined because of inadequate instrumentation.) Thus, all four 425-MHz peak-power values were comparable to the 1.3-GHz

threshold previously found (Frey, 1961), implying insensitivity to frequency in this range. However, the previously found 3-GHz peak-power threshold was considerably higher, about 5 W/cm², and the 8.9-GHz RFR was not perceived for peak-power densities as high as 25 W/cm². The author suggested that the rise in perception threshold from 1.3 GHz upward was related to the dependence of penetration depth on frequency. Noting the high ambient noise levels, he also suggested that the thresholds would be lower in quieter environments.

Frey (1962) also speculated about the possible sites and mechanisms of detection of RFR pulses, including RFR-induced changes of the electrical capacitance between the tympanic membrane and the oval window, detection in the cochlea, and interaction of the RFR with neuron fields in the brain. He discounted the first possibility because of the insensitivity of the RFR-hearing effect to head orientation relative to the RFR source, and indicated that the then-current experimental results were inconclusive about the other two possibilities.

Frey (1967) subsequently tried to resolve this point by studying the potentials evoked in the cat brain by exposure to 10-μs pulses within the range 1.2-1.5 GHz. However, the results were not conclusive and may have contained artifact.

Frey and Messenger (1973) exposed humans to pulsed 1.245-GHz RFR at 50 pps in an RFR anechoic chamber. In one set of experiments, the average power density was held at 0.32 mW/cm² and the pulse width was varied from 10 to 70 μs in 10-μs increments, yielding peak power densities from 640 to 91 mW/cm². In another set, the peak power density was held at 370 mW/cm² and the pulse width was varied over the same range, yielding average power densities from 0.19 to 1.3 mW/cm².

Four subjects with clinically normal hearing were given three trials each. The start of each trial was signaled optically. Following a variable interval of up to 5 seconds, each subject was first given a pulsed RFR signal for 2 seconds, the perceived loudness of which was to be taken as reference level 100. About 5 seconds later, the test RFR signal was presented for 2 seconds, and the subject was requested to indicate its numerical loudness relative to the reference. The results were displayed as logarithmic plots of the median values of perceived loudness versus peak power density and versus average power density. The point plotted for each test condition was the median value, without deviations, for all subjects and repetitions; no individual data were given.

In the peak-power-density plot, the loudness rose sharply from about 3 at 91 mW/cm² (70-μs pulses) to 60 at 125 mW/cm² (50-μs pulses); at the higher power densities, the sound level increased more slowly to a slightly rising plateau: to about 100 at 210 mW/cm² (30-μs pulses), 120 at 315 mW/cm² (20-μs pulses), and a slightly lower value at 630 mW/cm² (10-μs pulses). The plateau indicated that there is an optimal pulse-width band within which the perceived loudness depends on the peak power density. The author ascribed the loudness decrease at 630 mW/cm² to 10-μs pulses being shorter than optimal pulse width.

The plot of median loudness versus average power density showed more scatter, with the points ranging from about 60 at 0.19 mW/cm² (10-μs pulses) to a relatively flat maximum of 100 at 0.55 mW/cm² (30-μs pulses), diminishing to about 40 at 1.29 mW/cm² (70-μs pulses). The 1.29-mW/cm² dip was ascribed to 70-μs pulses being longer than optimal pulse width.

From their data, Frey and Messenger (1973) calculated that the peak-power-density threshold for perception of RFR pulses is about 80 mW/cm², a value much lower than those reported subsequently by Guy et al. (1975b) and by Cain and Rissman (1978), discussed later. In the absence of information on scatter of the responses by each subject and because subjective judgments of relative loudness may be imprecise, the accuracy of the results of Frey and Messenger (1973) could not be evaluated.

White (1963) reported that when the surface of a body is transiently heated by RFR-absorption (or electron bombardment), elastic waves are produced on the surface due to its thermal expansion. The author analyzed this process theoretically, with emphasis on the case of the input heat flux that varies harmonically with time, to relate the amplitude of the elastic waves to the characteristics of the input flux and the thermal and elastic properties of the body. Experiments with both electron impact and RFR-absorption verified the proportionality of the stress wave amplitude and absorbed power density, results that correlated well with the thermal and elastic properties of the heated medium.

The elastic waves were detected in all metals tested, in several carbon-loaded plastics, in water, and in a barium titanate piezoelectric crystal coated with silver. Mixing (the production of beat frequencies) was observed when two pulses of different RFR frequencies were absorbed simultaneously. A comparison of the elastic-wave stress amplitude with the radiation pressure showed that the former may be much greater than the latter, as demonstrated experimentally. When a barium titanate crystal was used to detect the elastic waves produced, heating by a single 2-μs pulse of electrons or RFR produced easily detectable signals at pulse power densities down to 2 W/cm², which corresponded to a computed peak surface-temperature rise of about 0.001 °C and which produced piezo-electric-crystal voltages ranging from about 1 to more than 60 mV per kW/cm² of absorbed power density.

Foster and Finch (1974) confirmed the findings of White (1963) that RFR pulses can produce acoustic transients in water, and showed by calculation that for short pulses, the peak sound pressure is proportional to the energy per pulse, whereas for long pulses, it is proportional to the incident power density. Using 2.45-GHz RFR in several combinations of pulse power density and pulse duration and a hydrophone immersed in saline (0.15-N KCl), they found that the transition between the two regimes occurs for pulse durations between 20 and 25 μs. The authors noted that the dependence of sound pressure on pulse duration and incident peak power density is consistent with those of Frey and Messenger (1973) at 1.245 GHz. They also found that such acoustic signals were not obtained in water at 4 °C (at which its thermal expansion coefficient is zero) and that the transient acoustic signal between 0 and 4 °C was reverse in polarity from that for temperatures above 4 deg °C, results that support the thermoelastic expansion hypothesis.

Sharp et al. (1974), in an experiment involving shielding regions of a subject's head from 1.5-GHz RFR pulses with RFR absorber, noticed that the apparent locus of the perceived sound moved from the head to the absorber. By using a sound-level meter to measure the delay times for acoustic propagation for distances of 0.3 to 0.6 m between the absorber and the microphone, they confirmed that the RFR pulses were transduced by the absorber into acoustic

signals. The pulses were 14 μs long and were randomly triggered at about 3 pps. By calculation, the power per pulse was 4.5 kW and the pulse power densities were 7.5-15 kW/m^2 (750-1,500 mW/cm^2) for the 0.3-0.6 m range of separations above.

Subsequent tests by Sharp et al. (1974) showed that varying the carrier frequency from 1.2 to 1.6 GHz or using 2.45 GHz made little difference in the level or quality of the sound. In addition, detectable sounds could be produced with various sizes and shapes of absorber, including pieces as small as 4 mm square by 2 mm thick, and in various types of absorber and in crumpled aluminum foil. The threshold pulse power for audibility was 275 W, yielding estimated pulse power densities in the range 0.46-0.92 kW/m^2 (46-92 mW/cm^2). Tests were also done with constant pulse repetition rates up to 500 pps, with the finding that: "The sound produced from the absorber seemed to track the repetition rate of the microwave pulses."

Guy et al. (1975b) determined power-density thresholds and modulation characteristics for the RFR-auditory effect in two volunteers. The authors exposed the back of the head of the two humans to RFR at 15 to 30 cm from the aperture of a horn in an anechoic chamber at an ambient noise level of 45 dB, with RFR-absorbent material around the vicinity of the subject to eliminate reflections. The RFR consisted of 2.45-GHz pulses of duration that was varied from 1 to 32 μs. For each duration, the RFR was presented in trains of 3 pps, with 100 milliseconds between pulses. In each case, the subject signaled when an auditory sensation was perceived. From standard audiograms taken prior to exposure, the hearing threshold of Subject 1 was normal, but Subject 2 had a deep notch at 3.5 kHz in both ears for both air and bone conduction.

For Subject 1, the threshold for RFR auditory perception was found to be a constant peak energy density (the product of peak power density and pulse duration) of 40 $\mu J/cm^2$ per pulse irrespective of pulse duration. At 3 pps, the corresponding average power density was 0.12 mW/cm^2. When Subject 1 wore ear plugs, the threshold peak was only 28 $\mu J/cm^2$ per pulse. The threshold for a pair of pulses spaced within several hundred microseconds was the same as for one pulse with the same total energy as the pair. Similar results were obtained for Subject 2, but the threshold peak energy density was 135 $\mu J/cm^2$ per pulse, about threefold higher than for Subject 1.

The authors remarked that each pulse was perceived individually by the subjects as a click and that trains of short pulses were heard as chirps of tones that corresponded to the pulse repetition rate. In addition, when the pulse generator was keyed manually, digital (Morse) code transmitted thereby could be interpreted accurately by the subjects.

The authors also studied the RFR-auditory effect in laboratory animals. Those studies are to be discussed in one of the planned reports on specific topics by the authors of the present report, as mentioned in the Introduction.

Guy et al. (1975b) and Lin (1976a, b; 1977a, b, c) analyzed postulated mechanisms for the conversion of RFR energy into acoustic energy in lossy dielectric materials. They concluded that thermal expansion forces induced by pulsed RFR, which are proportional to the square of the peak electric field, are much larger than the radiation pressure or the electrostriction produced by the same RFR pulses, and can generate in the head acoustic waves of the requisite magnitude for the hearing effect.

In Lin (1977c), equations developed for a spherical model of the head consisting of brain-equivalent material were used to obtain the acoustic resonant frequencies generated in the heads of guinea pigs, cats, and human adults and infants by exposure to RFR pulses. The results showed that the (fundamental and higher-harmonic) frequencies produced by RFR pulses are independent of the carrier frequency, but are dependent on head size, and specifically that the fundamental frequency is inversely proportional to the radius of the head. For humans, the predicted fundamental frequencies were 13 kHz for an adult and 18 kHz for an infant.

Cain and Rissman (1978) used 3.0-GHz RFR pulses to investigate the RFR-auditory effect in two cats, two chinchillas, one beagle, and eight human volunteers. For the animals, surface or brainstem-implanted electrodes were used to measure the responses evoked by audio clicks from a speaker and the responses to 5-, 10-, and 15-μs pulses. The results for the animals are to be discussed in the planned report mentioned above.

The eight humans were given standard audiograms for both air-conducted and bone-conducted sound. In addition, because the audiograms did not test hearing above 8 kHz, binaural hearing thresholds were determined for seven of the subjects for tone frequencies in the range 1-20 kHz. After those tests, the subjects were presented with 5-, 10-, 15-, and 20-μs RFR pulses at 1 pulse every 2 seconds. Each subject wore foam ear muffs during exposure, to reduce the ambient noise level (to 45 dB).

Subjects 1-5 could hear 15-μs pulses as clicks; their peak-power-density thresholds were respectively 300, 300, 300, 600, and 1,000 mW/cm². Subjects 1-5 could also hear 10-μs pulses, with peak-power-density thresholds of 1,800, 225, 600, 2,000, and 2,000 mW/cm². The only person able to perceive the 5-μs pulses was Subject 1, with a peak-power-density threshold of 2,500 mW/cm². By contrast, Subjects 6-8 could not hear 5-, 10-, or 15-μs pulses at the highest available peak power density but could perceive 20-μs pulses.

The authors did not find a correlation between the RFR results and the standard audiograms. However, they did note that a strong correlation existed between perception of RFR and hearing ability above 8 kHz as determined from the binaural thresholds. They also stated that their results are consistent with the hypothesis that a pressure wave in the human head induced by short RFR pulses contains a significant part of its energy above 8 kHz.

In brief summary of the study with human volunteers by Cain and Rissman (1978), only Subjects 1-3 could perceive 15-μs pulses, with a pulse-power-density threshold as low as 300 mW/cm² (energy-density threshold 4.5 μJ/cm²). Only Subject 2 could hear 10-μs pulses, with 225 mW/cm² (2.3 μJ/cm²) as the threshold; the thresholds for the other subjects were much higher than 300 mW/cm². Only Subject 1 could hear 5-μs pulses, but with a threshold of 2,500 mW/cm². Those thresholds were for 45 dB of ambient noise and could be higher in noisier environments. Thus, 300 mW/cm² can be taken as the nominal human RFR-hearing pulse-power-density threshold for pulse durations of about 10 μs or longer. It is noteworthy that these authors had exposed human volunteers to pulses of 3.0-GHz RFR at peak power densities as high as 2,500 mW/cm² with no apparent ill effects.

Tyazhelov et al. (1979) studied the qualities of the sounds perceived by humans from exposure to 800-MHz pulses. The parietal area of each subject's head was exposed to the open end of a waveguide fed from a 500-W source. The ambient noise level did not exceed 40 dB and was reduced by plugging the ears with stoppels or sound-conducting tubes. The pulse durations ranged from 5 to 150 μs. The pulses were presented either continuously at 50 to 2,000 pps (the latter for short pulse durations, to limit the average power density) or in pulse trains 0.1 to 0.5 seconds in duration at rates of 0.2 to 2.0 trains per second. Each person could be presented with sinusoidal audiofrequency (AF) sound waves independently of, or concurrently with, the pulsed RFR. The AF signals were presented to the subject by means of a pair of small hollow tubes extending from a speaker to the ears. The subjects had means for adjusting the amplitude, frequency, and phase of the AF signal to try to match timbre and loudness of the perceived RFR.

The high-frequency auditory limit (HFAL) of each subject for tones from 1 kHz upward was tested. Three subjects had HFALs below 10 kHz and could not perceive 10-30 μs RFR pulses, results that were consonant with those of Cain and Rissman (1978). Of 15 subjects with HFALs above 10 kHz, only one could not perceive the RFR pulses.

All of the perceptive subjects noted that 10-30 μs pulses delivered at 1,000 to 12,000 pps at peak power densities exceeding 500 mW/cm² produced sounds of polytonal character that seemed to originate in the head, and that the quality of the sound changed with increasing pulse repetition rate (PRR) in a complex manner. Loudness diminished sharply and the sound became more monotonal as the PRR was increased from 6,000 to 8,000 pps, but no more than three distinguishable tonal transitions occurred. Subjects with HFALs below 15 kHz were unable to distinguish between the sounds perceived from a 5,000-pps and a 10,000-pps signal, and subjects with more extended HFALs reported that the pitch for a 5,000-pps signal was higher than for a 10,000-pps signal.

The subjects were able to detect small (5%) shifts of PRR only in the 8,000-pps region. At the lower PRRs, the subjects erred on 100% of tests to detect the direction of PRR changes, indicating that increases of PRR were often perceived as decreases in pitch. For pulses of constant peak amplitude, loudness was perceived to: increase with duration from 5 to 50 μs, decrease from 70 to 100 μs, and increase again for 100 μs and upward. Such patterns of perception were exemplified by plots of threshold pulse power (normalized to the 10-kHz PRR threshold) versus PRR for a subject with a 14-kHz HFAL and for the another subject with a 17-kHz HFAL. The curves were roughly W-shaped, each with a central relative maximum at about 8 kHz. Also shown was a plot of mean threshold pulse power (normalized to the threshold at 50-μs pulse duration) for subjects unable to perceive any sounds for pulses longer than 50 μs. This curve was also W-shaped, with a central relative maximum within the range 100-120 μs of pulse duration.

After subjects matched the pitch and timbre of a 2-kHz acoustic tone to the perceived sound of a train of RFR pulses at 2,000 pps, they were asked to match the loudness of the acoustic tone with the loudness of the perceived pulses while the pulse duration was varied between 5 and 150 μs with the peak power held constant. No data were given. Instead, the relation between the ratio of the acoustic signal amplitude to the pulse power for the subjects (both quantities normalized to their respective thresholds) were merged into a

shaded area bounded by two straight lines through the origin. That graph also showed a straight line through the origin stated by the authors to represent the theoretical relationship between these quantities as predicted from the thermoelastic model. The entire shaded area was above the theoretical line, i.e., the ratios of acoustic amplitude to pulse power for all of the subjects were reported to be larger than predicted.

When acoustic tones above 8 kHz were presented concurrently with 10-μs to 30-μs pulses at PRRs slightly above or below 8 kHz, the subjects reported hearing beat-frequency notes. In addition, for a PRR of 800 pps, similar beat frequencies were perceived when the acoustic frequency was set slightly above or below harmonics of the PRR. Moreover, when the tone and PRR frequencies were matched and the subjects were allowed to vary the phase of the acoustic tone, cancellation of perception of the two stimuli could be achieved. By proper phasing, subjects with HFALs below 15 kHz could also achieve perception cancellation between a 10-kHz acoustic signal and a 5-kHz train of pulses.

The authors reported that the sensory characteristics (pitch and timbre) evoked by RFR pulses less than 50 μs in duration also were perceived when the heads of the subjects were lowered into seawater, with loudness diminishing roughly in proportion to the immersion depth and vanishing entirely with total immersion. For pulses longer than 50 μs, even partial immersion resulted in loss of perception.

In their discussion, the authors suggested that many of their results are consistent with the thermoelastic hypothesis, but that others, such as the suppression of the perception of a 5,000-pps train of RFR pulses by a 10-kHz acoustic tone, were at variance with that model.

3.1.1 SUMMARY ON THE RFR-AUDITORY EFFECT IN HUMANS

The results of the various investigations of the RFR-auditory effect in human volunteers are summarized in Table 31 (A, B, and C).

Authors	Effects Sought or Examined	Exposure Modality	Effects Reported	Notes & Comments
Frey (1961)	RFR-auditory effect in human volunteers.	6-μs pulses of 1.3-GHz RFR at 244 pps; 1-μs pulses of 3.0-GHz RFR at 400 pps. Ambient noise levels were about 70 and 80 dB, but with earplugs were lowered by about 25-30 dB.	The mean threshold of average power density for RFR perception was about 0.4 mW/cm² at 1.3 GHz for eight subjects and 2 mW/cm² at 3.0 GHz for seven subjects. The corresponding peak power densities were 270 and 5,000 mW/cm². Some subjects with various types of hearing losses had higher perception thresholds.	The author did not provide any variances or other statistical data. The subjects were unable to match the RFR sounds to audio sine waves. With band-pass controlled white noise, best match was obtained by removing all frequencies below 5 kHz.
Frey (1962)	The auditory effect in volunteers, some who had an audiogram notch (a significant hearing loss) around 5 kHz.	Pulses of 125, 250, 500, 1,000, and 2,000 μs of 425-MHz RFR at 27 pps; 2.5-μs pulses of 8.9-GHz RFR at 400 pps. The noise levels were 70-90 dB; with Flent ear stopples, the noise levels were lowered by about 20 dB from 100 Hz to 2 kHz and about 35 dB at 10 kHz.	The average-power-density thresholds for perception of 125-, 250-, 500-, and 1,000-μs 425-MHz pulses were 1.0, 1.9, 3.2, and 7.1 mW/cm², with peak power densities of 300, 280, 240, and 260 mW/cm², all comparable to the 1.3-GHz threshold in Frey (1961). However, the 3-GHz peak-power threshold in Frey (1961) was much higher, about 5 W/cm², and the 8.9-GHz RFR was not perceived for peak-power densities as high as 25 W/cm², differences ascribed by the author to smaller penetration depths.	The author speculated about possible sites and mechanisms of detection of RFR pulses, including interaction of the RFR with neuron fields in the brain, but found the data to be inconclusive. Again, no statistics were presented. Subjects who had the 5-kHz notch (and adequate hearing above and below 5 kHz) did not perceive RFR pulses as sound.
Frey and Messenger (1973)	Further human studies on the RFR-auditory effect.	1.245-GHz pulses at 50 pps; pulse width varied from 10 to 70 μs: Average power density held at 0.32 mW/cm² for peak power densities of 640 to 91 mW/cm²; peak power density held at 370 mW/cm² for average power densities of 0.19 to 1.3 mW/cm².	Each subject was requested to judge the loudness of pulsed-RFR signals relative to an initial reference signal. The median values of the loudness versus peak power density and versus average power density were graphed for each test, without deviations. The authors calculated that the peak-power-density threshold for perception of RFR pulses is 80 mW/cm², a value much lower than reported subsequently by Guy et al. (1975b) and by Cain and Rissman (1978).	No data for each subject were given. The accuracy of these results could not be evaluated because of the absence of data on the scatter of responses by each subject and because the subjective judgments of the relative loudness may be imprecise.
White (1963)	Elastic-wave theory of sound generation from thermal expansion due to transient surface heating.	Bombardment of the surfaces of metals, plastics, water, and piezoelectric crystal by RFR pulses or an electron beam.	Elastic waves were detected in each of the surfaces studied. Mixing (production of beat frequencies) was found when two pulses of different RFR frequencies were absorbed simultaneously. Use of a barium titanate crystal to detect elastic waves from heating with a single 2-μs pulse of electrons or RFR yielded easily detected signals at pulse power densities down to 2 W/cm², corresponded to a computed peak surface-temperature rise of 0.001 °C.	The author did a theoretical analysis of the process, based on assuming an input heat flux that varies harmonically with time, to relate the amplitude of the elastic waves to the characteristics of the input flux and thermal and elastic properties of the body.

TABLE 31A: RFR-AUDITORY EFFECT IN HUMANS

Authors	Effects Sought or Examined	Exposure Modality	Effects Reported	Notes & Comments
Foster and Finch (1974)	Further confirmation of the elastic theory of sound generation by RFR pulses.	They used 2.45-GHz RFR pulses in several combinations of pulse power density and pulse width, and a hydrophone immersed in salt water for detection.	The experimental results confirmed: the findings in water of White (1963); calculations showing that for short pulses, the peak sound pressure is proportional to the energy per pulse, but for long pulses it is proportional to the incident power density; and that the transition between the two peak-sound-pressure regimes occurs for pulse durations between 20 and 25 μs.	The authors also found that such acoustic transients were not obtained in water at 4 °C (where its thermal expansion coefficient is 0) and that acoustic signals between 0 and 4 °C were reverse in polarity from those for temperatures above 4 °C, results supporting the thermoelastic expansion hypothesis.
Sharp et al. (1974)	Transduction of RFR pulses into sound at the surfaces of RFR-absorbers.	14-μs pulses of 1.5-GHz RFR triggered randomly at about 3 pps while regions of the subject's head were shielded with RFR absorber. The power per pulse was 4.5 kW and the pulse power density ranged from 750 to 1,500 mW/cm^2.	With a sound-level meter to measure the delay times for acoustic propagation for distances of 0.3 to 0.6 m between the absorber and microphone, the authors confirmed that the absorber transduced the RFR pulses into acoustic signals. Varying the carrier frequency from 1.2 to 1.6 GHz or using 2.45 GHz made little difference in the level or quality of the sound. The threshold pulse power for audibility was 275 W, yielding estimated pulse power densities in the range 46-92 mW/cm^2.	The authors, while shifting the RFR absorber over various areas of the subject's head, noticed that the apparent locus of the sound moved from the subject's head to the absorber.
Guy et al. (1975b)	RFR-auditory power-density thresholds and modulation characteristics.	Exposures of the back of the subject's head to 2.45-GHz pulses of duration varied from 1 to 32 μs. Exposures were to trains of 3 pps each, with 100 ms between pulses. The ambient noise level was 45 dB.	For Subject 1 with a normal audiogram hearing threshold, the threshold for RFR auditory perception was a constant peak energy density of 40 $\mu J/cm^2$ per pulse irrespective of pulse duration. With ear plugs, the threshold was only 28 $\mu J/cm^2$ per pulse. Similar results were obtained for Subject 2, who had a deep notch at 3.5 kHz in both ears, but the threshold was 135 $\mu J/cm^2$ per pulse, or about three times higher than for Subject 1.	The two subjects studied were requested to signal when they perceived sound. They heard each pulse as a click, and heard pulse trains as chirps that corresponded to the pulse repetition rate. The subjects accurately interpreted Morse code transmitted by manual keying of the pulse generator.
Lin (1977c)	Analysis of equations of spherical models of human and animal heads of brain-equivalent material for acoustic resonant frequencies.	Theoretical paper on resonant frequencies generated by exposure to RFR pulses.	Analyzed were heads of guinea pigs, cats, and human adults and infants. The results showed that the fundamental and higher-harmonic frequencies produced by RFR pulses are independent of carrier frequency, but dependent on head size, with the fundamental frequency inversely proportional to the radius of the head.	The theoretically predicted fundamental frequencies for humans were 13 kHz for an adult and 18 kHz for an infant.

TABLE 31B: RFR-AUDITORY EFFECT IN HUMANS (CONTINUED)

Authors	Effects Sought or Examined	Exposure Modality	Effects Reported	Notes & Comments
Cain and Rissman (1978)	Experimental study of RFR-auditory effect in 2 cats, 2 chinchillas, 1 beagle, 8 humans.	5-, 10-, 15-, or 20-μs pulses of 3.0-GHz RFR at 1 pulse every 2 seconds. The humans wore ear muffs during exposure, to reduce the ambient noise level (to 45 dB).	Subjects 1-5 could hear 15-μs pulses, with peak-power-density thresholds of 300, 300, 300, 600, and 1,000 mW/cm^2. They also could hear 10-μs pulses, with thresholds of 1,800, 225, 600, 2,000, and 2,000 mW/cm^2. Only Subject 1 could hear 5-μs pulses, with a threshold of 2,500 mW/cm^2. By contrast, Subjects 6-8 could not hear 5-, 10-, or 15-μs pulses at the highest peak power density but could hear 20-μs pulses. In summary, 300 mW/cm^2 can be taken as the nominal human pulse-power-density threshold for pulse durations of 10 μs or longer.	Only results for the humans are summarized here. Seven subjects were given standard audiograms, and the thresholds for binaural hearing were determined for frequencies in the range 1-20 kHz. The authors had exposed humans to pulses of 3.0-GHz RFR at peak power densities as high as 2,500 mW/cm^2 with no apparent ill effects.
Tyazhelov et al. (1979)	The qualities of the sounds perceived by humans from exposure to RFR pulses. Small hollow tubes from a speaker to the ears were used to present audiofrequency sounds without or concurrent with the RFR.	The parietal area of each subject's head was exposed to 800-MHz RFR pulses of widths 5 to 150 μs, presented either at a pulse repetition rate (PRR) of 50 to 2,000 pps or pulse trains lasting 0.1 to 0.5 seconds at a rate of 0.2 to 2.0 trains per second.	Three subjects who had HFALs below 10 kHz could not perceive 10-30 μs pulses, results that were consonant with those of Cain and Rissman (1978). Only 1 of 15 subjects with HFALs above 10 kHz could not hear the pulses. Subjects with HFALs below 15 kHz were unable to distinguish between the sounds from a 5,000-pps and a 10,000-pps signal, and subjects with more extended HFALs heard a higher pitch for a 5,000-pps signal than a 10,000-pps signal. Subjects reported hearing beat-frequency notes when presented acoustic tones above 8 kHz concurrently with 10-μs to 30-μs pulses at PRRs just above or below 8 kHz; the subjects could cancel the perception of the RFR and audio when matching them in frequency, amplitude, and phase.	The high-frequency auditory limit (HFAL) of each subject was tested for tones from 1 kHz upward. The subjects had means for varying amplitude, frequency, and phase of the audio signals to try to match their timbre and loudness to the perceived RFR. The authors suggested that many of their results are consistent with the thermoelastic hypothesis, but that others, such as the suppression of the perception of a 5,000-pps train of RFR pulses by a 10-kHz acoustic tone, were at variance with that model.

TABLE 31C: RFR-AUDITORY EFFECT IN HUMANS (CONCLUDED)

3.1.2 CONCLUSIONS

From a variety of studies of the RFR-auditory effect in humans, [Frey (1961, 1962), White (1963), Frey and Messenger (1973), Foster and Finch (1974), Sharp et al. (1974), Guy et al. (1975b), Lin (1977c), Cain and Rissman (1978)], considerable understanding has been achieved about the interaction mechanisms that give rise to the effect. The book by Lin (1978) presents detailed discussions of the various mechanisms that had been proposed for the effect, and the experimental evidence that supports the theory that the effect is due to induction thermoelastic waves by RFR pulses at a boundary between tissues of dissimilar dielectric properties within the head, with propagation of the waves to the auditory system. Noteworthy are the findings of several studies that persons with specific hearing impairments are unable to perceive RFR pulses; the finding of Foster and Finch (1974) that the effect does not occur in water at 4 °C, where its thermal expansion coefficient is zero; and the peak-energy-density and peak-power-density thresholds for perception determined by Guy et al. (1975b) and Cain and Rissman (1978). [A peak power density of 300 mW/cm^2 is taken as the nominal perception threshold for humans of RFR pulses 10 μs or longer.]

However, the subsequent unusual findings of Tyazhelov et al. (1979) may indicate that specific aspects of the phenomenon are worth further study. On the other hand, it is noteworthy that Cain and Rissman (1978) had exposed human volunteers to pulses of 3.0-GHz RFR at peak power densities as high as 2,500 mW/cm^2 with no apparent ill effects. Thus, it is unlikely that persons perceiving RFR pulses would be affected adversely.

3.2 CUTANEOUS PERCEPTION

Among the few studies on human perception of RFR in the skin were those of Hendler and Hardy (1960), Hendler et al. (1963), and Hendler (1968), who compared the sensitivity of the forehead area to infrared radiation (IR) and RFR. Hendler (1968) is discussed below, with references to the two earlier papers as appropriate, because it includes most of the information in those papers plus some additional data.

To overcome the inadequacies of previous methods for measuring cutaneous temperature, Hendler and Hardy (1960) had developed a radiometic apparatus with the following capabilities:

(1) Temperature stimuli could be applied to the skin while permitting the concurrent measurement of the resulting changes in temperature with a sensitivity better than 0.001 °C per second and an absolute accuracy of ± 0.01 °C.

(2) The apparatus did not stimulate cutaneous sensations other than temperature (e.g., touch, pain, itch, etc.).

(3) Mechanical deformation of tissues, with resulting alteration in local cutaneous blood flow, was avoided.

(4) The stimulus was regulated and its intensity and distribution was controlled over the stimulated area.

(5) The apparatus permitted convenient application of stimuli of varying duration and tissue penetrability.

An insulating face shield was used to block all but a central 37-cm^2 circular area of the subject's forehead. A chopper rotating at 13 Hz (77 milliseconds per period) was positioned between the face shield and a heat source and between the face shield and a detector. The aperture areas of the chopper were designed so that the source or detector was open to the face shield during successive equal time intervals (about 30 milliseconds) of each rotation, but not to both simultaneously. The latter condition prevented reflection of source energy from the forehead to the detector and thereby permitted detection of only the radiant emission from the forehead. Thus, forehead cooling data could be determined virtually immediately after heating.

The chopper also amplitude-modulated the signals from the forehead at 13 Hz, thereby permitting the use of conventional detector-output amplification at that frequency. The amplified signals were rectified, filtered, and fed through a potentiometer to a strip-chart recorder. The potentiometer was used as a bucking-voltage source, to permit recording very small skin-temperature changes. A full-scale (10-inch) deflection of the recorder pen required 1.5 seconds, and with typical amplifier settings, such a deflection represented a temperature change of 2 °C.

Detection was based on the black-body characteristics of skin in the IR region. Examination of the reflectance spectra of black and white skin showed large differences between them in the visible and near-IR regions from about 0.4 to 2 microns (with maxima respectively at about 1 and 0.7 microns), but that the two curves were virtually coincident in the far-IR region from about 2 to 20 microns. Also, the black-body emission curve for 35 °C, approximately normal forehead temperature, covered the latter range, with a peak at about 8 microns.

The detector, housed in an evacuated chamber having a far-IR-transparent window, consisted of a blackened target with a thermocouple attached. Black-body emission for a 245-°C source covers the range from about 3 to 40 microns, with a peak at about 5 microns. Therefore, the IR source used was a hot plate electrically maintained at any fixed temperature between 200 and 300 °C. The radiation reaching the subject's skin from this source was controlled with a thermally insulated shutter, which could be rotated silently to regulate the duration of exposure. Calibration of the intensity within the face shield (to within about 3%) was done with a portable radiometer.

The RFR source described in Hendler and Hardy (1960) and Hendler et al. (1963) was a magnetron-powered 3-cm (10-GHz) pulse generator set to produce 0.4-μs pulses at 2,500 pps. Magnetron output was fed through a waveguide to a horn placed, when used, in the same relative position as the hot plate. The peak and average output powers were 60 kW and 60 W. The RFR was controlled either manually by on-off switching or automatically with a microswitch operated by a revolving cam programmed for appropriate on-off sequences.

Data obtained with a 10-cm (3-GHz) pulsed source (2-μs pulses at 300 pps) terminated with a horn were presented only in Hendler (1968). However, because of the larger size of the RFR apparatus, direct measurement of skin temperature by radiometry was not feasible. The subject was placed in the far field of the horn within an anechoic chamber, behind a shield that again limited the RFR to the forehead area.

Absorption of RFR energy of each frequency by the skin was determined with a skin "simulant" consisting of a hollow acrylic disc 0.55 cm thick for 10 GHz (3 cm) and 1.5 cm thick for 3 GHz, with polyethylene faces about 0.02 mm thick. Each disc was filled with water and was equipped with internal thermocouples and an electric heater wire. The disc was mounted in the aperture of the face shield. Calibration was done by measuring the electric power required to raise the water temperature by known values in given time intervals, thus permitting calculation of the power required raise the water temperature by the same amount as by RFR during corresponding time intervals.

The absorption coefficient, calculated from equation 2-2-1 on page 154 of Hendler (1968) and from the electrical properties of skin, was 4.9 per cm for 10 GHz and 1.2 per cm for 3 GHz. The corresponding penetration depths (reciprocals) were about 0.2 cm and 0.8 cm. The penetration depths given in Durney et al. (1978), p. 38, are respectively about 0.4 cm and 1.8 cm or twice those in Hendler (1968). The reasons for the discrepancies are obscure except that the equation cited by Hendler appears to be in error. Moreover, with the stated values of dielectric constant and specific resistance of skin at 10 GHz, the equation yielded a small and therefore probably inaccurate difference between two nearly equal numbers. However, Hendler (1968) also noted that individual values of absorption coefficient deviated as much as 50% from the mean.

Each experimental session lasted about 10 minutes. The subjects were given auditory warning signals before each stimulus. Successive stimuli were separated by at least 40 seconds, to allow the skin to return to its initial temperature. When IR was used to change skin temperature, each subject orally reported temperature sensation (warm or cool) or no sensation (neutral) every 10 seconds, and the response was noted immediately on the skin-temperature record. Because of the changes in sound associated with the use of the RFR generators, each subject was provided with sound-attenuating ear muffs, and a low-frequency masking noise was provided. Subjects exposed to RFR were also provided with two manual switches, one for each hand, to continuously record a warm or cool sensation by closing the appropriate switch, or no sensation by closing neither switch. The IR results are discussed first.

From curves of temperature increase for IR heating (with the hot plate) versus time, thermal inertia (product of thermal conductivity, mass density, and specific heat) was determined for skin. The thermal inertia values were found to remain stable over heating periods lasting 140 seconds, and the mean for three subjects was 108 cgs units, a finding of importance relative to heating with pulsatile IR, discussed later.

Detailed examination of forehead temperature records of seven subjects exposed to the IR showed that the best correlate of the reported temperature sensations was the time rate of change of the skin temperature when the skin remained within a few degrees of its normal level. No consistent relationship was found between the temperature-sensation reports and the time derivative of the time rate of change of skin temperature, the skin temperature per se, or the increment of skin temperature.

Representative IR results were given that were based on 788 reports of warm, cool, and neutral sensations by one experienced subject during eight experimental periods. During those periods, skin temperature was varied from

slightly higher than 32 °C to about 36 °C but not by more than 0.6 °C during any one experimental period. Those results were plotted as percentages of the reports of each sensation versus the measured time rate of change of the skin temperature (over the range from -0.01 to +0.01 °C per second). Even though the authors visually drew the curve for each sensation (a straight line each of positive and negative slope respectively for warm and cool and an inverted U for neutral), instead of statistical curve fitting, the correlations were evident. Taking the 50% probability level for each sensation as indicating the threshold for that sensation yielded a threshold skin-temperature rate of change between +0.001 and +0.002 °C per second for warm and between -0.005 and -0.006 °C per second for cool.

The authors noted some exceptions to the relationship between sensation and rate of change of skin temperature. First, during the periods when the skin temperature was not changed, only 48.6% of the reports were neutral; of the remaining reports, 19.5% were cool and 31.9% were warm. Second, rapid spontaneous fluctuations of skin temperature due to irregularly occurring convective heat losses were not accompanied by sensation reports consistent with the skin-temperature changes actually measured. Third, when the skin was heated or cooled appreciably and allowed to return spontaneously to its normal level, initial reports of cool were made irrespective of the direction of the change.

High levels of pulsatile IR were applied to the skin of the forehead of an experienced subject for short durations, without and with skin blackening with india ink. The radiometric apparatus was not used, because its frequency response was limited. Instead, the source was a Variac-controlled 150-W incandescent lamp covered with a near-IR (1-3 microns) filter. A leaf-type camera shutter having a wide-open aperture area of 25.65 cm² was placed over the face shield. The opening times of the shutter were varied to produce square-wave pulses of thermal energy of duration 39 to 570 milliseconds.

At each shutter setting (pulse duration), various intensities were tried until a level was found for which half the stimuli yielded reports of warm sensation. That level was taken to be the warmth threshold for that pulse duration. A plot of threshold level versus pulse duration (over the domain 39-570 milliseconds) yielded a reciprocal (constant-product) relationship, a result taken as indicating some common change within the skin under the assumption that the warmth sensation was the same for each pair of values.

The authors analyzed the IR-induced intracutaneous temperature changes with the one-dimensional heat-conduction equation, and the solution for each threshold level and pulse duration was plotted as temperature increment versus depth into skin. The shapes of the curves were similar, each curve showing diminution of temperature increment with depth, with the curve for the highest threshold intensity and shortest pulse yielding the highest rise in surface temperature and the largest (negative) slope. Especially noteworthy was that the curves crossed one another within the depth range 150-200 microns, in which region the temperature rise was about 0.02 °C. Thus, taking 50 microns as the approximate thickness of the epidermis, the authors associated the threshold of warmth sensation with thermal stimulation of the subcutaneous region. They suggested that rapid surface-temperature fluctuations would not be very effective in stimulating this region (because of the thermal inertia of skin), which would account for the absence of responses to the spontaneous convective heat losses noted above.

Responses to heating with 10-GHz RFR yielded sensation reports that were more variable than those with IR. Among the results were those indicating a functional dependence of threshold surface-temperature increase on exposure time that was different for 10-GHz RFR than for IR. The surface-temperature increase diminished with exposure time (reciprocity) for IR, whereas it rose linearly with exposure time for 10-GHz RFR. The curves crossed at about 1.4 seconds, for which the threshold surface-temperature increase was about 0.033 °C. The curve for 3 GHz was not shown because no direct measurements of skin temperature at this frequency were made. However, the authors remarked that a curve calculated from the known absorption coefficient of skin at 3 GHz would be below and roughly parallel to the 10-GHz curve.

The only 3-GHz data presented (in Hendler, 1968) was a plot of threshold stimulus intensity versus exposure time, with similar plots for 10 GHz and far IR. Both RFR curves extended to exposure durations of 5 seconds, but the IR curve to only 3 seconds. Reciprocity was evident for all three curves, with the 3-GHz curve above that for 10-GHz and the latter above the IR curve, results consonant with penetration-depth considerations. As representative numerical results, the threshold stimulus intensities for 1-second exposures to 3 GHz, 10 GHz, and IR were respectively about 14.3, 4.5, and 1.2 mcal per second per cm^2 (60, 19, and 5 mW/cm^2). For 5-second exposures, the 3- and 10-GHz thresholds were respectively about 7.6 and 3.0 mcal per second per cm^2 (32 and 13 mW/cm^2); by extrapolation, the 5-second threshold for IR was about 0.05 mcal per second per cm^2 (0.2 mW/cm^2).

Among the other notable results with 10-GHz RFR were delays in responses between stimulus initiation and first report of warmth sensation (onset delay) and between stimulus termination and end of warmth sensation (offset delay). In a typical experiment, the average onset and offset delays were respectively 2.4 and 6.6 seconds. The authors remarked that casually placing the hand directly in front of the RFR horn to obtain greater intensity yielded warmth that persisted for several minutes after the hand was removed and that the subjects did not respond to suprathreshold rates of skin-temperature change in a manner that could be accounted for by the hypothesis that this measure is the effective stimulus for sensation as for IR.

Justesen et al. (1982) subsequently determined the warmth thresholds by exposing the forearm of each of six volunteers to vertically polarized far-field 2.45-GHz CW RFR within an anechoic chamber for 10 seconds at aperiodic intervals of about 30 seconds. For exposure, each subject was located behind an RFR-absorbing partition within the chamber, with the ventral surface of the forearm vertically placed against a 15-cm aperture in the partition. Subjects were similarly exposed to IR from focused quartz lamps through an aperture of the same size in a Styrofoam partition. During the threshold measurements, the fans used for driving air through the chamber were inactivated, and the ambient temperature and relative humidity averaged 25 ± 2.0 °C and 50 ± 5%, respectively. Calibrations of RFR and IR power densities were done at the center of the aperture (in the absence of the subject) with a Narda Model 8316B E-field probe and a Hardy radiometer, respectively.

IR SARs were determined for a cylindrical red-latex-balloon model filled with 0.9% NaCl in distilled water and secured against the aperture. The length and diameter of the model were 15.5 and 2.25 cm, and the mass was 62 g.

A Vitek temperature probe suspended at the geometric center of the model was used to measure the temperature rise. IR exposures for 10 minutes at 10.71 mW/cm^2 yielded a temperature rise of 0.9 °C, which corresponded to an SAR of 6.3 W/kg or 0.59 W/kg per mW/cm^2.

RFR SARs were similarly determined, but with a saline-filled cylindrical model of length 15.9 cm, diameter 5.8 cm, and mass 420 g, values that more closely corresponded to the mass and profile of the part of the human forearm exposed through the aperture. The model was exposed at 70 mW/cm^2 until a rise of exactly 0.5 °C was attained, which required 394 seconds. The calculated SAR from these values was 5.31 W/kg, or 0.076 W/kg per mW/cm^2 (not 0.74 $\mu W/g$ per mW/cm^2 as stated in the text). The power incident on the model, obtained by multiplying 70 mW/cm^2 by the profile area (about 88 cm^2) exposed through the 15-cm aperture, was 6.16 W. The rate of energy absorption in the model was 2.23 W or only about 36% of the incident power, i.e., about 64% of the incident power was scattered.

The ranges of power densities used were 0-70 mW/cm^2 in 5-mW/cm^2 steps for RFR, and 0-5.5 mW/cm^2 in 0.5-mW/cm^2 steps for IR. On-off switching of the RFR was done at the source. However, IR switching was done with a manually operated shutter because of the long rise time of the source lamps.

Three men and three women were the subjects for the RFR experiment and two of each gender participated in the IR experiment. The profile of each subject's forearm within a 15-cm aperture was drawn, and the area within the profile was measured with a planimeter. The trials were conducted with the subject in the dark, and lighting of a bulb before each trial signaled the subject to place the arm in the appropriate position. The 10-second exposure was done within 5-15 seconds of the signal, after which the experimenter elicited, via an intercom system, a yes or no from the subject regarding perception of the stimulus.

Thresholds for perception of RFR and IR were ascertained by the random double-staircase method (Cornsweet, 1962), in which the stimulus level to be presented during a given trial was determined as follows: If the subject reported perception of the stimulus in the preceding trial, the stimulus level was lowered by a randomly determined multiple of steps ("stairs"); if the subject responded negatively, the level was raised similarly. The randomness of the size of the multiples precluded discovery by the subject of any pattern of successive stimuli. This procedure was continued until 13 transitions (reversals of intensity direction) occurred, and the threshold was defined as the mean of stimulus intensities over the final 10 transitions.

The RFR and IR threshold data and forearm profile area for each subject were tabulated, and the means were calculated separately for the men and women. The mean thresholds for RFR perception by the men and women were respectively 25.27 and 28.88 mW/cm^2, a nonsignificant difference. Their IR thresholds were 1.48 and 2.00 mW/cm^2, also a nonsignificant difference. However, the Pearson product-moment correlation, r, between the RFR and IR thresholds for all 6 subjects (without regard to gender) was high ($r=0.97$) and reliable ($p<0.02$). The mean profile areas for the men and women were 122.67 and 91.33 cm^2, respectively, a significant difference, but the correlation between threshold power density and profile area was only 0.26 ($p<0.1$) for RFR and 0.62 ($p>0.1$) for IR.

The RFR thresholds for the six subjects had a range of 28.85 (from 15.40 to 44.25) mW/cm² and a grand mean of 26.74 mW/cm². The deviance, defined as the ratio of the range to the grand mean and used as an index of instability, was 108%. The range of IR thresholds for the four subjects was 1.10 (from 1.45 to 2.55) mW/cm², with a grand mean of 1.74 mW/cm² for a deviance of 63%. Thus, the grand mean RFR-power-density threshold was about 15 times higher than the IR threshold. None of the four subjects exposed to both RFR and IR reported any difference in sensory quality between the two stimuli.

The threshold of RFR energy absorbed by each subject during a 10-second exposure was calculated from the threshold incident power density, the exposed forearm area, and the dosimetric data from the saline models (with absorption efficiency of 0.36 as noted above). The resulting range of threshold energies was 9.15 J (6.43 to 15.58 J), with a grand mean of 10.16 J, for a deviance of 90%. The threshold IR energy was similarly calculated (with 1.0 absorption efficiency); the range was 0.86 J (1.38-2.24 J), with a grand mean of 1.83 J and a deviance of 47%. Thus, the amount of RFR energy absorbed for threshold stimulation was about fivefold higher than for IR. Also, the threshold-energy deviance for each stimulus was smaller than its threshold-power-density deviance. The authors therefore suggested that threshold energy absorption is a more stable predictor of just-noticeable warming by either RFR or IR than threshold power density.

Because of the high correlation between the RFR and IR thresholds, the warmth sensed is believed by the authors to be due to stimulation of the same superficially located thermoreceptors of the skin. The fifteenfold difference in power density and the fivefold difference in absorbed energy between RFR and IR thresholds for stimulation were ascribed in part to the large scatter (about 64%) of the incident RFR (versus virtually no IR scatter) and in part to the much larger penetration depth of the RFR.

The authors noted that Hendler (1968) had found that exposure of a 37-cm² area of the human forehead to 3-GHz RFR (shown as 3000 GHz, a typographic error) for 4 seconds required a mean threshold for warmth of 33.5 mW/cm². By extrapolating Hendler's data, the authors obtained a threshold of about 27 mW/cm² for 10-second exposures, a value very close to the grand mean, 26.7 mW/cm², found in this study. In addition, the mean IR threshold (1.7 mW/cm² obtained in this study) was comparable to the human-forehead IR threshold (extrapolated to 10 seconds) reported by Hendler et al. (1963).

The adequacy of the RFR-SAR determinations described in this paper may be questioned because the authors used a thermal probe at the geometric center of the saline model to monitor the RFR-induced temperature rise of the water during a 394-second (6.6-minute) exposure; they appear to have ignored the variation of energy-absorption rate with depth and the effects of surface cooling. In particular, no mention was made of any measures taken to minimize heat loss from the saline model or of whether the temperature of the saline was equilibrated by stirring or other method during exposure. If the authors had not taken such precautions, then the thresholds of energy-absorption could be considerably inaccurate. Another point open to question is how valid were the extrapolations of the threshold curves to 10-second exposure durations. However, these comments do not gainsay the qualitative findings of this study.

Justesen et al. (1982) also performed a pilot study on whether the onset and offset delays in perceiving 10-GHz RFR reported by Hendler et al. (1963)

would also occur with 2.45-GHz RFR. The forearm of one subject was exposed at 70 mW/cm^2 for periods varied randomly from 10 to 60 seconds, with the subject required to signal as soon as warming was perceived and when it was no longer perceived. The onset delay ranged between 3.5 and 6.0 seconds. The offset delay usually ranged from 3 to 5 seconds, but during the longer exposures (30 and 60 seconds), the warmth sensation sometimes faded before end of exposure, an effect attributed to sensory adaptation. The authors suggested that if this sensory adaptation is a general property of RFR-heating, it may help account for the difficulty of rodents to learn to escape from or avoid high levels of RFR.

3.2.1 SUMMARY ON CUTANEOUS PERCEPTION OF RFR

The results of the studies on cutaneous perception of RFR and IR by human volunteers are summarized in Table 32.

3.2.2 CONCLUSION

The high threshold power densities for cutaneous perception of RFR found by Hendler and coworkers and by Justesen et al. (1982), particularly those at 2.45 GHz and 3.0 GHz (at which penetration is relatively deep), indicates that such perception may not occur at RFR power densities well above those in the current exposure guidelines. Therefore, the absence of such perception during RFR-exposure at such higher levels should not be taken as indicative of the safety of such exposure.

Authors	Effects Sought or Examined	Exposure Modality	Effects Reported	Notes & Comments
Hendler and Hardy (1960) Hendler et al. (1963) Hendler (1968)	Sensitivity of the skin of the human forehead to RFR and infrared (IR).	RFR-exposures were: to 0.4-μs, 10-GHz pulses at 2,500 pps, or to 2-μs, 3-GHz pulses at 300 pps. IR-exposures were to a hot plate (black body) held at about 245 °C (emission peak at 5 microns).	The IR data indicated that the best correlate of the reported temperature sensations was the time-rate-of-change of the skin temperature when the skin remained within a few °C of its normal level. The thresholds for this endpoint were between +0.001 to +0.002 °C/s for warm sensation and -0.005 to -0.006 °C/s for cool sensation. In an IR plot, the increase in surface temperature diminished with exposure time (showing reciprocity), whereas in an RFR plot for 10 GHz, it rose linearly with exposure time. Plots were given of the threshold stimulus intensity versus exposure time for 3 GHz, 10 GHz, and far IR. Reciprocity was evident in all three curves, with the 3-GHz curve above the 10-GHz curve and the latter above the IR curve, results consonant with respective penetration depths. Threshold stimulus intensities for 1-second exposures to 3 GHz, 10 GHz, and IR were about 60, 19, and 5 mW/cm², respectively.	A central 37-cm² area of the of each subject's forehead was exposed. IR detection was done with a radiometer, using the black-body characteristics of the skin in the IR region. Auditory warning signals were given before either IR or RFR stimulus. On stimulation with IR every 10 seconds during 10-minute sessions, each subject orally reported feeling either a warm, cool, or no sensation. On stimulation with RFR, each subject operated either or neither of two manual switches to record a warm, cool, or no sensation.
Justesen et al. (1982)	Warmth thresholds of the human forearm to far-field 2.45-GHz CW RFR and to IR.	Exposures were for 10 seconds each, at aperiodic intervals of 30 seconds, to 2.45-GHz CW RFR with the forearm parallel to the E-vector.	Three men and 3 women were subjects for the RFR experiment and 2 of each gender participated in the IR experiment. The ranges of power densities used were 0-70 mW/cm² in 5-mW/cm² steps for RFR, and 0-5.5 mW/cm² in 0.5 mW/cm² steps for IR. The thresholds for RFR perception by the 6 subjects ranged from 15.40 to 44.25 mW/cm² with a mean of 26.74 mW/cm². The IR thresholds for the 4 subjects ranged from 1.45 to 2.55 mW/cm², with a mean of 1.74 mW/cm². The corresponding range of RFR threshold energies was 6.43 to 15.58 J, with a mean of 10.16 J. The IR range was 1.38-2.24 J, with a mean of 1.83 J. Thus, the amount of RFR energy absorbed for threshold stimulation was about five times higher than for IR.	For exposure, each subject was placed behind an RFR-absorbing partition, with the ventral forearm surface against a 15-cm aperture in the partition. Using an aperture of the same size in a Styrofoam partition, the subjects were similarly exposed to IR from focused quartz lamps. IR and RFR SARs were determined with saline-filled cylindrical balloons secured against the apertures.

TABLE 32: CUTANEOUS PERCEPTION OF RFR

3.3 RFR SHOCK AND BURN

Although it was known that RFR can cause electric shock in the body or burns in tissue under specific circumstances, specific exposure limits were not included in previous standards for human exposure to RFR. Guy (1985), however, noted that such effects were considered in choosing the 300-kHz lower frequency limit of the then current ANSI (1982) standard.

Rogers (1981) stated the problem as follows: "When a person touches an electrically energised object, he may experience an adverse effect. If the object is energised by a radio-frequency (rf) source, the predominant contact hazard is burning of tissue at the point of contact and arises when the current drawn from the object exceeds a certain value. This rf burn hazard exists on various transmitting aerials and simple precautions can be taken to avoid it. However, such a hazard can also arise on metallic objects excited by radiation from transmitting aerials in their vicinity and this paper is devoted to this aspect."

In that paper, a simple apparatus ("RF Burn Hazard Meter") was described to measure the RF currents passing through a human in shoes standing on a ground plane. Part of the apparatus consisted of a brass tube excited by an RF source, with the source connected to the ground plane. When the subject touched the tube with a finger, a loop consisting of the source, tube, body of the subject, and ground plane was closed to form the single-turn primary of a current transformer. The rest of the apparatus was the transformer secondary winding and its connections via diode detectors, resistors, and capacitors to a DC current meter. Using this apparatus, the current levels that yielded a barely perceptible sensation ("perception" current) and that caused discomfort ("let-go" or "hazard" current) were measured for frequencies in the MF band (0.3-3 MHz) and the HF (3-30 MHz) band.

The author indicated that the perception current and let-go current for contact with the tip of the forefinger were both about twice those for contact with the back of the forefinger, and were even higher for large-area contact with the palm. The results for 50 persons tested with the back of the forefinger showed a mean hazard threshold current of about 200 mA for the band 2-20 MHz.

The paper was devoted primarily to possible shipboard hazards from the metallic structures in the vicinity of onboard radiating antennas. Included in the paper were measured and calculated data for various structures and distances. The author concluded: "The measurements described indicate an rf burn hazard threshold of about 200 mA for the HF band and show that many shipboard structures can be excited sufficiently by own ship transmissions in this band to present rf burn hazards to personnel. They show also that cranes can be potent sources of rf burn hazards...It is to be noted that rf burn hazards are present on structures when irradiated at field strengths much lower than the maximum permissible for human exposure. For example the measurements on the crane reported above show that the electric field for rf burn hazard threshold is about 10 V/m compared, for example, to the American National Standards Institute for the band 3-30 MHz." [Referring to the ANSI (1974) standard, which specified a maximum electric field of 200 V/m for the frequency range 10 MHz to 100 GHz].

Gandhi and Chatterjee (1982) used the quasi-static approximation (Deno, 1974; Bracken, 1976) to calculate the short-circuit currents induced in metallic objects (a 2.44-m x 1.22-m metal roof, a 50-ft metal fence, a compact car, and a fork-lift truck) and in a human (height 1.75 m, mass 68 kg), when each object is in a vertically polarized electric field at frequencies in the range 10 kHz to 10 MHz, and with each object assumed to be isolated from ground by 5 cm of insulation. They then calculated the incident electric fields necessary to produce threshold-perception and let-go currents for a human in conductive finger contact with each object. The threshold-perception current was defined as the smallest current that produces a tingling or pricking sensation due to nerve stimulation. The authors noted that the sensation changes from tingling to internal heat at frequencies above about 100-200 kHz. Let-go current was defined as the maximum value at which a human can still release an energized conductor with muscles directly stimulated by that current.

The authors used the experimental data on human perception-threshold and let-go currents of Dalziel and Mansfield (1950), Dalziel and Lee (1969), and Rogers (1981) for their calculations. These data were reproduced as log-log plots of perception-threshold and let-go currents versus frequency. The perception-threshold current showed a linear rise from about 0.4 mA at 10 kHz to about 14 mA at 150 kHz, with a slower rise to about 100 mA at 20 MHz. The let-go current also showed a linear rise, from 6.4 mA at 10 kHz to about 85 mA at 150 kHz, and a slower linear rise to about 200 mA at 20 MHz.

By using the capacitance-to-ground value for each object and the ratio of its electrostatically coupled short-circuit current to the unperturbed vertical field measured at 60 Hz (Deno, 1974; Bracken, 1976), Gandhi and Chatterjee (1982) obtained the effective area (S) and height (h) of the object. They assumed that these values of S and h are also reasonably valid for frequencies in the range 10 kHz to 3 MHz because the fields are quasi-static for objects with largest dimension that is much smaller than the free-space wavelength.

Log-log plots of the calculated values of unperturbed electric field (E) necessary to create threshold-perception and let-go currents in a human in finger contact with each object were presented. For each object, the value of E for threshold perception was constant with frequency in the approximate range 10-100 kHz; the numerical values were about 250, 160, 80, and 20 V/m for the roof, fence, car, and truck, respectively. In the range 10 kHz to 10 MHz, the E values for the car and truck did not change substantially but those for the roof and fence decreased respectively to about 35 and 20 V/m at 10 MHz. The plots of E for let-go current versus frequency were similar: the plateaus for the roof, fence, car, and truck in the range 10-100 kHz were about 1040, 850, 440, and 110 V/m, respectively, with diminution for the roof and fence to less than 100 V/m at 10 MHz and smaller decreases for the car and truck.

The authors stated: "A simple analysis based on the equivalent circuit representation of a human in conductive contact with an ungrounded, metallic object in a quasi-static HF field points out that there may be situations where the thresholds of perception and let-go can be exceeded for fields considerably lower than the ANSI recommended guideline of 615 [sic] V/m, the far-field equivalent E-field associated with a power density of 100 mW/cm^2 in the frequency band 0.3 to 3.0 MHz [ANSI, 1982]...The above effects will not occur if the conducting objects are grounded or insulated at the points of possible contact."

Chatterjee et al. (1986) measured the complex body impedance (magnitude and phase) and the threshold currents for perception and pain for of ages between 18 and 70 years for the frequency range 10 kHz to 3 MHz. They defined the threshold-perception current for pain as the smallest current for which the subject reported "very uncomfortable sensations (similar to but more intense than that for perception) for which he/she will definitely not continue to touch the electrode any more."

Shown separately for men and women were mean body-impedance data (and SDs) versus frequency for barefoot subjects standing on a ground plane and grasping a brass-rod electrode that was insulated from the ground plane. Both the magnitude and the phase decreased monotonically with frequency; however, the magnitude for women was significantly higher than for men at corresponding frequencies. At 10 kHz, for example, the mean values for women and men were respectively about 630 and 520 ohms. The difference in mean phase at each frequency was not significant. Use of an index finger moistened with 0.9% saline to touch a metal-plate electrode insulated from the ground plane yielded qualitatively similar results, but of much higher magnitudes, about 1900 and 1700 ohms at 10 kHz, respectively.

For men, the mean threshold-perception currents for finger contact rose linearly with frequency from about 4 mA at 10 kHz to about 40 mA at 100 kHz and remained at the latter value from 100 kHz to 3 MHz. The curve for women was parallel to that for men, but about 25% lower; by analysis of variance, the difference was highly significant. The results for grasping contact were similar. The curves of threshold currents for pain with finger contact versus frequency also rose roughly linearly to maxima at about 100 kHz, but decreased slightly with frequency in the range 100 kHz to 3 MHz. At 10 kHz, the mean threshold currents for pain in men and women were respectively about 10 and 6.5 mA, but their maxima at 100 kHz were nearly the same, about 14.5 mA. The authors noted that threshold-current values for 10-year-old children can be obtained from those for male adults by using a scaling factor of about 60%.

The sensation reported by the 367 men and women for frequencies below 100 kHz was tingling or pricking, localized in the area adjacent to the region of contact on the finger or hand; for frequencies above 100 kHz and finger contact with the plate electrode, the sensation was warmth or heat in the area below and around the plate electrode; with grasping contact, warmth or heat was felt in the hand and wrist. To determine more accurately the frequency for transition from tingling to warmth, data were obtained for some subjects at 50 and 70 kHz. At 50 kHz, the sensation reported was always tingling, but at 70 kHz, some subjects reported tingling and others warmth. Moreover, when the current was raised slightly for those who reported tingling, the sensation changed to warmth. In addition, for frequencies above 100 kHz at which warmth was felt, when the current was adjusted to be equal to the perception threshold, pain was reported typically within 10-20 seconds, an effect that was not observed for frequencies below 100 kHz.

Also determined in this study were: the short-circuit currents induced in humans at local AM broadcast stations (operating at 630, 700, and 1500 kHz) and at Coast Guard and Navy communication antenna sites in Hawaii (operating at 13.6, 23.4, 146, and 3105 kHz) while barefoot or wearing safety, leather-soled, or rubber-soled street shoes; the short-circuit currents induced in

various vehicles; and the currents induced in humans in contact with these vehicles. Among the findings were that electrical safety shoes and gloves provide adequate protection only at frequencies less than about 1 and 3 MHz, respectively. The measurements of induced short-circuit current indicated reductions to 55% of the barefoot values with rubber-soled shoes, 63% with safety shoes, and 85% with leather-soled shoes.

The mean body impedances and threshold-perception currents were used to calculate the E-fields for threshold perception by grounded humans in finger contact with a compact car, a van, and a school bus. The results for adult males and 10-year-old children were plotted versus frequency in one set of graphs, and for adult females in another set. Similar sets of curves were obtained for threshold-perception E-fields with grasping contact. Also presented were similar sets of curves of the threshold E-fields for pain versus frequency for finger contact with such vehicles.

The threshold-perception curves for finger contact by men, women, and children were all entirely below 632 V/m, the value recommended in ANSI (1982) for the range 0.3-3.0 MHz, with peaks at approximately 100 kHz in ascending order respectively for the school bus, van, and compact car. (The curves for the bus and van crossed at frequencies above 100 kHz.) Thus, currents from all three vehicles could be sensed at fields smaller than those recommended by ANSI (1982) for the range 0.3-3.0 MHz. For grasping contact, the school-bus threshold-perception curves for all three groups were also below the ANSI (1982) value over the entire frequency range; those for the other vehicles were below that level except within frequency ranges of various sizes encompassing their respective peaks at 100 kHz.

The curves of pain-threshold E-field for finger contact with each type of vehicle were entirely below 632 V/m except for the curve for men in contact with the compact car. That curve exceeded 632 V/m in the range approximately 10-80 kHz, with a maximum of about 850 V/m at 30 kHz. All the other curves also had broader maxima at frequencies less than 100 kHz than those at 100 kHz for threshold perception.

The authors had measured the capacitance-to-ground of a GMC van that was well insulated from ground at a local AM broadcasting station operating at 700 kHz. The result was 1045 pf. They used this value in a calculation of the current through the hand of a grounded human in conductive contact with the handle of such a van immersed within a 3-MHz, 632-V/m field and obtained 879 mA. Based on this result and on an effective cross-sectional area of 11.1 cm^2 for the wrist, they estimated that the corresponding local SAR in the wrist would be about 1045 W/kg.

The results of this study were presented in considerably more detail in a final report by Gandhi et al. (1985a). Given in Appendix B of that report (although not directly related to possible shock and burn hazards from contact with metallic objects) were formulas for calculating the local SARs in cross sections of the human leg (ankles, just below and above the knee, and two other thigh locations) for a human (barefoot and with safety shoes) immersed in a vertical field at the levels specified in ANSI (1982) for the range 0.3-30 MHz. (These levels are 632 V/m for frequencies f in the range 0.3-3 MHz, and are 1897/f for f in the range 3-30 MHz.)

Those formulas include the currents induced in the bodies, derived by the quasi-static approximation, and the effective cross-sectional areas of interest, derived from the geometric areas and specific conductivities of the tissues involved. Also presented were experimentally determined human values of normalized current (in mA per V/m) that demonstrated the validity of the quasi-static approximation to frequencies up to about 40 MHz. With those formulas, calculations based on assuming that half the body current flows through each leg indicated that SARs as high as 182 W/kg could occur in the ankle region. These results were also published in Gandhi et al. (1985b).

Guy and Chou (1985) performed an extensive study on possible hazards to humans from exposure to fields in the VLF-MF (10 kHz to 3 MHz) range, directed principally toward the quantitation of thresholds and establishment of safety standards against such hazards. They noted that though SAR is generally used to quantify internal energy absorption, other quantities may be more important in the VLF-MF band for this purpose, because the amounts of energy absorbed by humans exposed to fields in that frequency range are relatively low but can cause direct neuromuscular effects from electric shock, and that local tissue damage may result from electric contact between the subject and metallic objects in the field. In addition to SAR, the important quantities include the total electric current, I, in the body resulting from exposure while in contact with objects or surfaces in free space, and the current density, J, through various cross sections of the body.

Those authors also noted that maximum energy coupling occurs when the longest dimension of the body is parallel to the electric vector, and that for exposure in this orientation to plane waves and most VLF-MF antenna sources, absorption from the magnetic component is more than an order of magnitude smaller than absorption from the electric component, so any restrictions on electric-field exposure will ensure restrictions on the corresponding magnetic fields that are more conservative by at least a factor of ten.

In this report, the prior work on possible shock and burn hazards was reviewed, and vast quantities of experimental and calculated data were presented, including:

1) Impedances for humans and various vehicles, and for humans in contact with such vehicles under various ground conditions.

2) Measurements of open-circuit voltage and short-circuit current for humans and vehicles in high-strength electric fields, with the humans barefoot or wearing standard leather-soled shoes, standard rubber-soled shoes, sandals, or stockings.

3) Impedance distributions along the axis of the body and limbs versus frequency for 275 adult men and women of various ages, shapes, and sizes.

4) Weights and heights of the populations above, and circumference and diameter of middle finger, legs, arms, torso, shoulders, neck, and head at 5-cm intervals along their body and limb axes.

5) Thresholds for electrical-stimulation perception versus frequency for the finger, arm, and ankle.

6) Threshold currents and current densities for perception of electric shock by the average-sensitive, 0.5-percentile least-sensitive, and 0.5-percentile most-sensitive subpopulations.

7) Induced body currents, current densities, SAR distributions, and average SARs in all parts of the bodies of some subjects in the low-, medium-, and high ranges of weight for exposure to fields under various conditions, including: free space, feet grounded, hand grounded, and hand in contact with an object drawing 1 mA of current.

8) Current flow in the bodies of subjects when in contact with various vehicles in VLF and MF fields at field strengths measured from ground level to a height of 7 ft.

9) Human exposures at the following sites to the frequencies indicated:

10.2 kHz	Haiku, HI
23.4 kHz	Lualualei, HI
24.8 kHz	Jim Creek, WA
146 kHz	Lualualei, HI
1 MHz	KOMO Radio, Vashon Island, WA

An important finding was that highest local SARs occur in the ankles of the subjects, a result also found by Gandhi et al. (1985a). In the rationale of the ANSI (1982) guidelines, exposures at maximum local spatial SARs as high as 8 W/kg (averaged over any gram of tissue and over any 0.1-hour period) were permitted if the whole-body-averaged SARs do not exceed 0.4 W/kg. In this context, Guy and Chou (1985) noted that exposure to fields in the VLF-MF range would have to be restricted to 97 V/m to avoid exceeding the 8-W/kg limit.

In their conclusions, Guy and Chou (1985) stated: "At the present time this study is far from complete and will require additional work before any final conclusions can be made concerning safety guidelines for the VLF-MF frequency range." They also noted: "Based on the measurements carried out under this contract, it appears that not enough attention has been placed on spark discharge hazards. This type of insult can produce a very unpleasant stimulus and an involuntary startle reaction which can occur at exposure fields much less than that required to produce a perceived steady state current."

3.3.1 SUMMARY ON RFR SHOCK AND BURN

The studies on the conditions for the occurrence of shocks and burns from exposure to RFR are summarized in Table 33 (A and B).

Authors	Effects Sought or Examined	Exposure Modality	Effects Reported	Notes & Comments
Rogers (1981)	Threshold currents for barely perceiving a sensation and for feeling discomfort from touching or grasping a body energized by RF.	Touching or grasping contact with a brass tube excited from a grounded RF source at frequencies in the MF (0.3-3 MHz) or the HF (3-30 MHz) bands.	Using the apparatus, the author measured the threshold "perception" current (for barely perceptible sensation) and the threshold "let-go" or "hazard" current (that caused discomfort) for frequencies in the MF band (0.3-3 MHz) and the HF (3-30 MHz) band. The perception current and let-go current for contact with the tip of the forefinger were both about twice those for contact with the back of the forefinger, and were even higher for large-area contact with the palm. For 50 persons who touched the tube with the back of the forefinger, the mean hazard threshold current was about 200 mA for the band 2-20 MHz. The author remarked that RF burns could occur from touching structures exposed at field strengths much lower than those in the ANSI (1974) guidelines.	The brass tube was part of a simple "RF Burn Hazard Meter" for measuring the RF currents passing through a human in shoes standing on a ground plane. A subject touching the tube thereby became part of a closed loop through which the RF current flowed and was measured.
Gandhi and Chatterjee (1982)	The authors calculated short-circuit currents induced in 4 metallic objects and a human, all assumed insulated from ground, when each is exposed to an RF electric field at 10 kHz to 10 MHz. They also calculated the RF fields for threshold-perception and let-go currents in a human in finger contact with each object. Used were the threshold data of Dalziel and Mansfield (1950), Dalziel and Lee (1969), and Rogers (1981).	The electric fields were assumed to be vertically polarized. The metallic objects were: a 2.44-m by 1.22-m metal roof, a 50-ft metal fence, a compact car, and a fork-lift truck. The human was assumed to be of height 1.75 m, mass 68 kg.	Log-log plots of the calculated values of electric field E necessary to create threshold-perception and let-go currents in a human in finger contact with each object showed that E for threshold perception was constant for each object in the approximate range 10-100 kHz, with values about 250, 160, 80, and 20 V/m for the roof, fence, car, and truck. In the range 10 kHz to 10 MHz, the E values for the car and truck did not change much but those for the roof and fence decreased to about 35 and 20 V/m at 10 MHz. Plots of E for let-go current were similar: the plateaus for the roof, fence, car, and truck in the range 10-100 kHz were about 1040, 850, 440, and 110 V/m, with diminution for the roof and fence to less than 100 V/m at 10 MHz and smaller decreases for the car and truck. The authors noted that threshold E values higher than those in the ANSI (1982) guidelines may be encountered.	The authors defined threshold-perception current as the smallest current that yields a tingling or pricking sensation due to nerve stimulation. They indicated that the sensation changes from tingling to internal heat at frequencies above about 100-200 kHz. Let-go current was defined as the maximum current for which a human can still release an energized conductor with muscles directly stimulated by that current. The experimental threshold data of the cited authors were reproduced as log-log plots of perception-threshold and let-go currents versus frequency.

TABLE 33A: RFR SHOCK AND BURN

Authors	Effects Sought or Examined	Exposure Modality	Effects Reported	Notes & Comments
Gandhi et al. (1985a) Chatterjee et al. (1986)	Measurements of human body impedances and threshold currents for perception and for pain versus frequency in the range from 10 kHz to 3 MHz. Currents induced: in humans near local AM stations and Coast Guard and Navy sites while barefoot or with 3 types of shoes; in a small car, a van, and a school bus; and in humans in contact with such vehicles.	Barefoot humans on a ground plane while grasping an insulated brass rod or touching an insulated metal plate with a saline-wetted index finger. AM-station broadcast frequencies: 630, 700, 1500 kHz; Coast Guard and Navy frequencies: 13.6, 23.4, 146, 3105 kHz.	For men, the mean threshold-perception currents for finger contact rose with frequency from about 4 mA at 10 kHz to 40 mA at 100 kHz and remained there from 100 kHz to 3 MHz. The plot for women was parallel, but about 25% lower, a highly significant difference. The results for grasping contact were similar. The plots of threshold currents for finger-contact pain rose to maxima at about 100 kHz but decreased slightly in the range 100 kHz to 3 MHz. At 10 kHz, the mean threshold currents for pain in men and women were about 10 and 6.5 mA, but their maxima at 100 kHz were both about 14.5 mA. Electrical safety shoes and gloves were found to provide adequate protection only at frequencies less than about 1 and 3 MHz, respectively. The threshold-perception plots for finger contact by men, women, and children were entirely below 632 V/m, the value recommended in ANSI (1982) for the range 0.3-3.0 MHz.	The sensation for frequencies below 100 kHz was tingling or pricking localized in the area next to the contact region; above 100 kHz, the sensation for finger contact with the plate was warmth or heat in the area below and around the plate; with grasping contact, warmth or heat was felt in the hand and wrist. The sensation at 50 kHz was tingling, but at 70 kHz, some subjects reported tingling and others warmth, with a change for the former to warmth at higher current.
Guy and Chou (1985)	Shock and burn hazards in the VLF-MF range; perception and shock thresholds under various conditions. Human impedances and distributions thereof within human bodies; impedances of various vehicles and of humans in contact with such vehicles. Induced body currents and current densities in humans; SAR distributions and mean SARs in all parts of the human body.	Various human and vehicular exposure modalities at 10 kHz to 3 MHz. Human exposures to specific VLF-MF frequencies at sites in Hawaii and Washington State.	Highest local SARs occur in the ankles of humans, a result also found by Gandhi et al. (1985a). Permitted in ANSI (1982) were exposures at maximum local spatial SARs as high as 8 W/kg if whole-body-averaged SARs do not exceed 0.4 W/kg, which led the authors to remark that exposure to fields in the VLF-MF range would have to be restricted to 97 V/m to avoid exceeding the 8-W/kg limit. They also indicated that for VLF-MF exposure, absorption from the magnetic component is usually at least 10 times lower than from the electric component, implying that exposure guidelines should reflect such differences.	The authors noted that in the VLF-MF band, quantities other than SAR may be more important because energy absorption by humans in that frequency range are relatively low but can cause direct neuromuscular effects from electric shock, and that local tissue damage may result from electric contact between subjects and RF-exposed metallic objects.

TABLE 33B: RFR SHOCK AND BURN (CONCLUDED)

3.3.2 CONCLUSION

Rogers (1991), Gandhi and Chatterjee (1982), Gandhi et al. (1985a), Guy and Chou (1985), and Chatterjee et al. (1986) had determined the threshold currents for perception or pain from touching or grasping conductive objects charged by immersion in fields at frequencies in the range 0.3 to 30 MHz (the MF and HF bands), e.g., fences and vehicles in the vicinity of broadcast stations. Those results indicated that electric shocks and/or burns can occur for RFR well below the maximum levels specified in the then prevailing ANSI (1982) guidelines for that frequency range. Thus, the data obtained by those authors served as the basis for the limits on induced and contact currents in the ANSI/IEEE (1992) exposure guidelines for controlled and uncontrolled environments, shown respectively in Tables 3 and 4 herein.

4 OVERALL SUMMARY

The findings of the various epidemiologic/occupational and inadvertent RFR-exposure studies are summarized in Table 7 (General Health), Table 9 (Congenital Anomalies), Table 14 (Ocular Changes), Table 24 (Cancer Incidence), and Table 29 (VDTs and pregnancy outcomes). Other RFR effects studied with human volunteers are summarized in Table 31 (RFR-Auditory Effect), Table 32 (Cutaneous Perception), and Table 33 (RFR Shock and Burn).

5 OVERALL CONCLUSION

Considerable weight should be given to the findings of well performed studies involving actual or presumed human exposure to RFR despite the known limitations of such studies, because of the problems and uncertainties in animal studies related to interspecies differences. Analyses of the findings of the various epidemiologic studies on the effects of RFR-exposure (either occupationally or from residing in the vicinity of RFR emitters) on general health, and the findings of the studies with human volunteers, produced no unequivocal evidence that chronic exposure to RFR at levels at or below those specified in the ANSI (1982) or the ANSI/IEEE (1992) exposure guidelines was implicated in any reported detrimental health effects. Especially important, the human studies analyzed yielded no scientific evidence to substantiate the following claims:

1. An association of congenital abnormalities with prenatal exposure of mothers to RFR or with prior RFR-exposure of the fathers.

2. Ocular damage from chronic exposure to low levels of RFR (i.e., at or below previous or current exposure guidelines).

3. Induction or promotion of cancer by RFR-exposure.

4. That persons more susceptible to added physiological burdens, such as children and chronically ill or aged individuals, would be adversely affected by chronic exposure to RFR within current exposure guidelines.

6 <u>REFERENCES AND INDEX</u>

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